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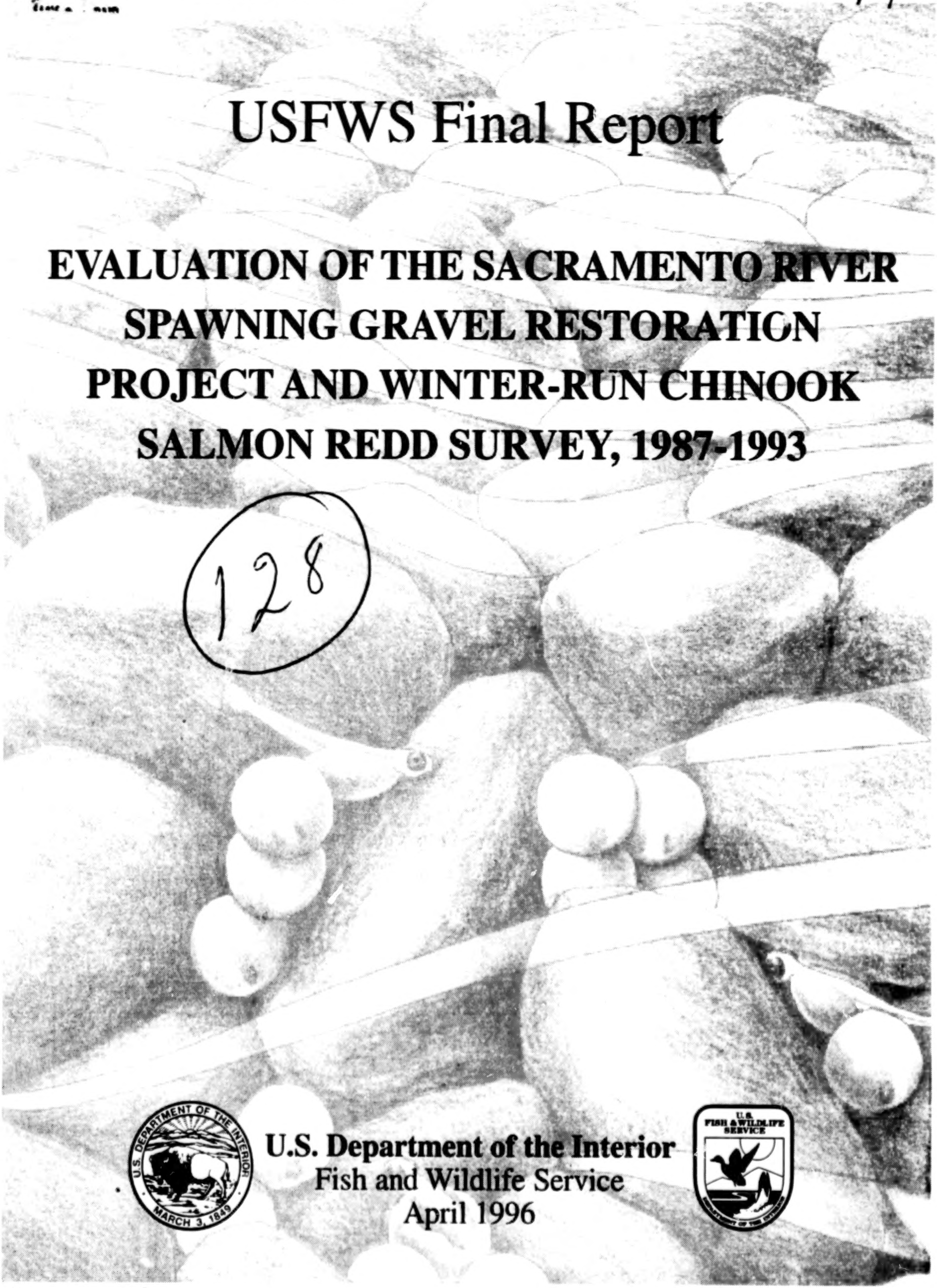

USFWS Final Report

EVALUATION OF THE SACRAMENTO RIVER SPAWNING GRAVEL RESTORATION PROJECT AND WINTER-RUN CHINOOK SALMON REDD SURVEY, 1987-1993

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USFWS Final Report

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January 1996

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Evaluation of the Sacramento River Spawning Gravel Restoration Project and Winter-Run Chinook Salmon Redd Survey, 1987 - 1993

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Abstract.—To improve spawning habitat available to the endangered winter-run chinook salmon *Oncorhynchus tshawytscha* and other chinook salmon runs, the California Department of Water Resources began a gravel restoration project in the upper Sacramento River in 1990. A total of 100,000 yd^3 of spawning-sized gravel was added to the river at 9 sites. Gravel was placed along the river bank to be dispersed during high flows or was graded below the water line. To evaluate the effectiveness of this project, detailed substrate maps of the riverbed were developed below 5 sites prior to gravel dumping. These were used as a baseline to measure changes in the amount of spawning substrate available to chinook salmon. During the first two years following placement, flows in the upper Sacramento River were inadequate to move the gravel; the majority of gravel remained where originally placed. However, adult chinook salmon were observed spawning in gravel at some of these new sites during this period. Spring rains in 1993 resulted in flow releases of approximately 50,000 ft^3/s from Keswick Dam. Gravels at all sites were displaced downstream. Although much of the gravel was completely washed out of the study sites, an improvement in the percentage of good and fair spawning substrate in the upper Sacramento River available to chinook salmon did occur.

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Introduction

Loss of gravel recruitment is believed to be a major contributing factor to declining chinook salmon *Oncorhynchus tshawytscha* productivity in the upper Sacramento River below Keswick Dam (Parfitt 1980; Buer 1984; Hallock and Fisher 1985; Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). The Upper Sacramento River Fisheries and Riparian Management Plan ranks restoration of spawning gravel third in a list of twenty action items related to upper Sacramento River fishery restoration (Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). Spawning gravel depletion has been most severe in the stretch of the Sacramento River from Keswick Dam (River Mile [RM] 302.0) to the mouth of Cottonwood Creek (RM 273.5; Figure 1). Historically, gravel in this river reach had been recruited from above Shasta Dam or by bank erosion. Because these sources of gravel are no longer available, the plan recommended placement of about one million yd^3 of spawning gravel in this reach of river.

Subsequent to these recommendations, the California Department of Water Resources (CDWR) has added approximately 100,240 yd^3 of spawning gravel to the upper Sacramento River (CDWR 1990; Bigelow 1992; Elko 1992). This gravel was added at 8 sites between Salt Creek (RM 301.0) and Shea Levee (RM 290.0; Figure 1). The California Department of Fish and Game (CDFG), with funding from the U. S. Bureau of Reclamation, has also placed spawning gravel in the upper Sacramento River. In 1988, 16,000 yd^3 of spawning gravel were dumped on the river bank at the mouth of Salt Creek and in 1989, 8,000 yd^3 were also added to the river bank immediately below Keswick Dam.

Preliminary surveys of the Salt Creek gravel placement by SCUBA divers from this office during the fall of 1989 revealed gravel introduced in 1988 had moved as far as 0.25 mi downstream in water depths over 20 ft. This exceeded expectations as no high flow releases had occurred from Keswick Dam (>14,000 ft^3/s). Additionally, fall-run adult chinook salmon were observed constructing redds in this gravel. Suitable spawning areas previously did not exist at this location (Vogel and Taylor 1987). These observations indicate high potential of successful gravel placement programs for fishery restoration in the upper Sacramento River.

Northern Central Valley Fish and Wildlife Office (NCVFWO) undertook an evaluation of gravel movement into the river as part of the multi-agency effort to improve spawning habitat available to Sacramento River chinook salmon. The goal of the gravel restoration project is to increase spawning habitat available to chinook salmon in the upper Sacramento River. Specific study objectives were to:

1. Develop maps of spawning substrate available to chinook salmon prior to gravel placement at 5 sites selected for intensive study.

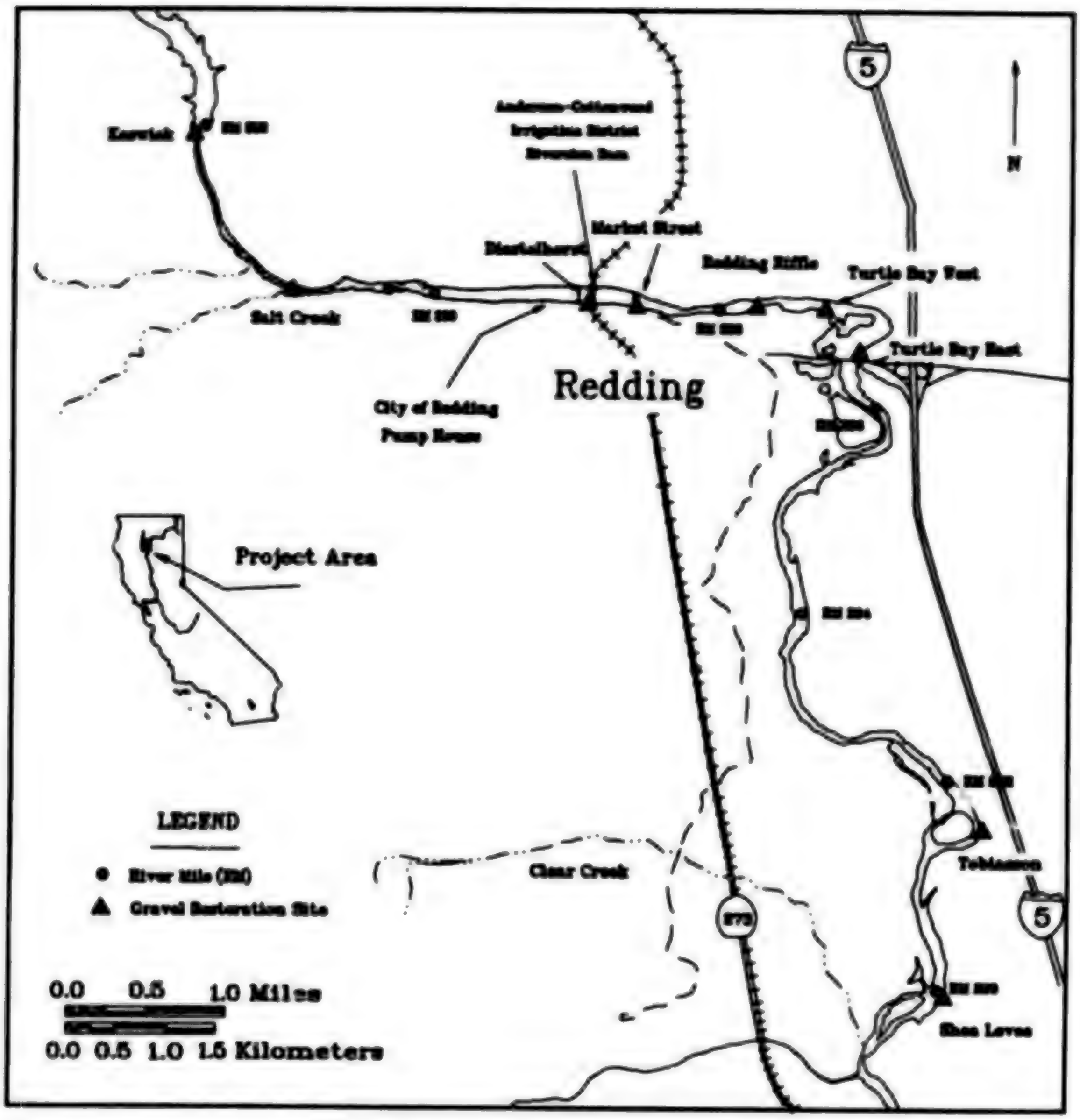

Figure 1.—Upper Sacramento River gravel restoration sites (adapted from Elko 1992).

2. Develop immediate post-placement maps of gravel additions.

3. Document gravel movement after one flood event to detect changes in the amount of spawning habitat available.

4. Measure quality of habitat created by added gravel.

5. Monitor use of gravel sites by adult chinook salmon.

6. Count redds of winter-run chinook in an index area as an indication of the abundance of adult fish. Redd counts could be influenced by this project because one restoration site, Diestelhorst, lies within the index area, and two sites, Keswick and Salt Creek, are upstream of the index area.

Study Area

The Sacramento River is the largest river system in California. This river and its numerous tributaries drain parts of the Coast Range, Klamath Mountains, Cascade Range, and Sierra Nevada. It originates near Mt. Shasta and flows approximately 400 mi south-southwest until it joins the San Joaquin River and empties into San Francisco Bay at Suisun Bay (Figure 2). At its headwaters above Shasta Reservoir, the Sacramento River is a cool, clear mountain stream. Near Redding, the river becomes broader and slower, but below Jelly's Ferry it enters Iron Canyon and forms a series of rapids (Reynolds et al. 1990). At Red Bluff, it becomes an alluvial stream controlled by its own water and sediment discharge (Reynolds et al. 1990).

Three dams—Shasta, Keswick, and Red Bluff Diversion—have been constructed on the river and have contributed to changes in flow patterns and temperature regimes. Shasta Dam is located at approximately RM 314 on the Sacramento River. Construction on Shasta Dam began in 1938 and was completed in 1944. This dam retains water from the Sacramento, McCloud, and Pit rivers to form Shasta Reservoir. Completion of this dam permanently denied access to approximately 50% of historical salmon spawning habitat (Moffett 1949). When full, Shasta Reservoir is 35 mi long and stores 4,493,000 acre-feet of water at 1,066 ft elevation.

Keswick Dam is located at RM 302 on the Sacramento River. Construction of Keswick began in 1941 and was completed in 1951. Aside from receiving Sacramento River water released from Shasta Dam, Keswick Reservoir also receives interbasin flows from the Trinity River. Water from the Trinity River Basin is diverted via the Clear Creek Tunnel through the Judge Francis Carr Powerhouse into Whiskeytown Reservoir. From here, Trinity water can be diverted into Keswick Reservoir via the Spring Creek power conduit to the Spring Creek Powerplant. No fish ladders exist at Keswick Dam; further upstream passage of migrating

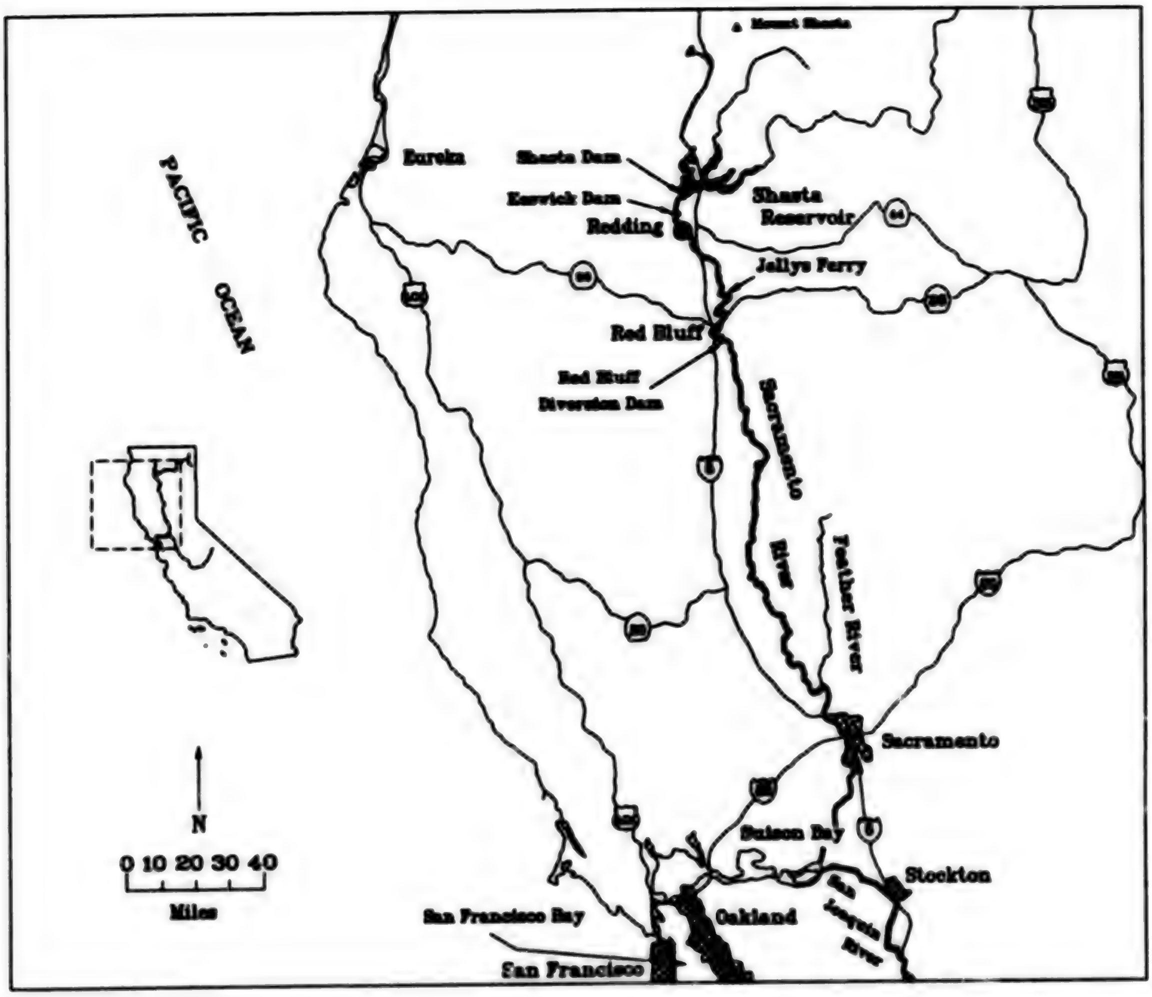

Figure 2.—Sacramento River system in Northern California.

adult salmon and steelhead trout is completely blocked. Coleman National Fish Hatchery (NFH) uses a fish trap built into this facility for collection of adult salmon.

Red Bluff Diversion Dam, located at RM 243 on the Sacramento River, was completed in 1964. This dam serves as a water diversion to the Tehama-Colusa and Corning canals for irrigation purposes. The structure has been shown to impede upstream progress of migrating adults and subjects juveniles migrating downstream to increased mortality by entrainment or increased predation (Vogel et al. 1988). Coleman NFH also utilizes a fish trap located in the east ladder for chinook salmon broodstock collection.

The Anderson-Cottonwood Irrigation District (ACID) Dam is located at RM 298 in Redding . The ACID Dam is usually installed mid to late April and removed in October or November. Although a small fish ladder does exist, this dam hinders the upstream migration of adults.

Regulation of flow releases from Shasta, Keswick, and Whiskeytown reservoirs is complex. While the Sacramento River supplies water for local industrial, agricultural, and domestic uses in the Central Valley, as well as the rest of California, it is also a major salmon and steelhead trout producer. Four distinct races of chinook salmon inhabit the Sacramento River system: spring, fall, late-fall, and winter. Each run is named for the time of year the majority of adults enter freshwater to begin their upstream spawning migration. Populations of all four races of chinook have declined by over 50% since the 1950's (Hallock and Fisher 1985). In recent years, numbers of returning winter-run adults have plummeted from a record high of 117,808 in 1969 to a low of 189 in 1994. This led to the listing of the winter-run chinook salmon as "threatened" under the Endangered Species Act in 1990. On January 4, 1994 the Sacramento winter-run chinook salmon was reclassified to "endangered", effective February 3, 1994 (59 FR 440). The State of California listed winter-run chinook salmon as "endangered" in 1989.

Our study area extends from Keswick Dam (RM 302) south to the confluence of Clear Creek (RM 289; Figure 1). This area encompasses the primary spawning area for the endangered winter-run chinook salmon.

Methods

Spawning-sized gravel (1-4 in) was added to 8 sites in the upper Sacramento River between RM 302 and 289 during 1990 and 1991 by CDWR (Figure 1, Table 1). Gravel was applied to study sites in one of two ways. At dump sites, gravel was piled along the bank of the river where it would be available for high flows to disperse it throughout the channel. At graded sites, gravel was smoothed with a rubber-tired front end loader to an elevation below the low-flow water surface level, providing gravel which would be immediately available as spawning habitat. A light-colored gravel (tracer rock) was mixed in with gravel added at the

Market Street Bridge and Keswick sites to aid the assessment of gravel movement. Tracer rock was also added to the Shea site, but not mixed in with the other gravel.

Five sites were selected for intensive evaluation: Salt Creek, Diestelhorst, Market Street Bridge, Redding Riffle, and Shea Levee (Table 1). Other sites which received gravel during 1990 and 1991 but are not under intensive survey are Tobiasson, Turtle Bay West, and Turtle Bay East (Table 1; Appendices A through G). The site immediately below Keswick Dam is also being observed. High river flow was expected to distribute these gravels throughout the river, improving existing and creating additional spawning habitat. Gravel restoration sites selected for intensive monitoring were used to document gravel movement and use of spawning gravel by adult chinook.

Table 1.—Gravel restoration sites with river mile location, total yd^3 of gravel placed, and type of application (Elko 1992).

Site	River mile	Total placement (yd^3)	Type of application	Notes
Salt Creek*	301.0	24,330	dump	north bank
Diestelhorst*	298.8	1,240	graded	south side of river just downstream of railroad trestle
Market Street Bridge*	298.4	11,080	graded	both upstream and downstream of bridge along south bank
Redding Riffle*	298.3	12,540	graded	south side of river
Turtle Bay West	297.1	15,620	graded	
Turtle Bay East	296.6	5,250	graded	
Tobiasson	291.6	12,450	dump	
Shea Levee*	290.0	17,730	dump	east bank across and upstream from Clear Creek confluence

*sites selected for intensive evaluation

Gravel Movement Evaluation

SCUBA techniques were employed to allow direct observation of riverbed substrate. Each section of the river being mapped was divided into a grid. Floats were placed equidistant across the river at the beginning and end of each survey section to mark longitudinal transects. Bright flagging, every 50 ft along shore, marked cross sections. A diving flag float was towed behind the boat directly above the divers for safety and to identify their position in the river. Divers were radio equipped and relayed observations to personnel on the surface. Personnel in a second boat were able to precisely record these observations on maps using the shore flagging, position of the divers, and the longitudinal river floats. Data on type of bottom substrate and presence of redds were recorded. In areas too shallow to use this SCUBA technique, substrate type was recorded by personnel on foot, snorkeling, or in a boat. Substrate was categorized into 5 classes describing suitability for spawning (adapted from Vogel and Taylor 1987):

Good - Substrate predominantly composed of gravel and cobble (90-100%), 1 to 6 in diameter with most substrate 2 to 4 in diameter, boulders or fines scarce.

Fair - Substrate predominantly composed of gravel and cobble (50-90%); proportion of gravels to cobbles smaller than in the "good" category.

Poor - Substrate composed almost entirely of large (>6 in) cobbles or gravels and fines abundant.

None - Substrate not meeting the above criteria, for example bedrock, sand, very large rocks, or boulders.

Unknown[1] - Obscured by weed growth or unobserved.

Substrate maps were developed for each of the 5 sites selected for intensive monitoring prior to addition of gravel. Mapping started at a point just upstream to approximately 0.25 mi downstream of the placement site with the exception of Market Street Bridge and Shea Levee. Gravel was added both upstream and downstream of the Market Street Bridge and only the downstream area was mapped before gravel addition. At Shea Levee mapping started slightly downstream of the placement site. The area of each substrate category present was calculated using DesignCad 2D software (American Small Business Computers, Inc. 1992) as baseline information. Initial placement of gravel was also mapped at each site soon after introduction.

Gravel surveys were conducted at all 9 sites during 1992. However, because little movement was noted, detailed substrate maps were not developed. Visual observations of each gravel placement site were done by foot, aerial survey, or SCUBA survey. Aerial photographs were taken during surveys conducted by CDFG in April 1992.

Following a high-flow event in the Sacramento River drainage early in 1993, substrate was again mapped just below each of the 5 sites chosen for intensive monitoring. Areas were estimated for each substrate category. Comparison of pre- and post-gravel placement maps were made to determine effectiveness of hydraulic movement of the gravel into the system. Comparisons between years were made using percentages of each substrate class.

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[1] The Unknown category was added to Vogel's and Taylor's classification scheme because a substantial amount of substrate was not observable due to weed cover— particularly in the Lake Redding area or in swift currents further upstream.

To the extent possible, substrate maps were also developed for the entire reach of river between ACID and Keswicks dams. This data was compared to 1987 data (Vogel and Taylor 1987) to gain further insight into gravel movement through that section of river.

Gravel Utilization

Aerial photographs of new gravel sites were made during surveys conducted by CDFG in 1991, 1992, and 1993. Personnel from this office accompanied CDFG on these flights to document use of new gravel by adult chinook salmon. These surveys were conducted biweekly, weather permitting, during the salmon spawning season and weekly during winter chinook salmon spawning.

Winter-Run Chinook Salmon Redd Surveys

Redd counts were conducted in the Lake Redding area of the Sacramento River during July and early August 1987, 1988, 1990, 1991, 1992 and 1993 using the same SCUBA techniques described under *Gravel Movement Evaluation*. Winter-run redds were distinguished from other chinook redds by a lack of accumulated debris and algal growth covering the redd. Locations of old redds were also noted. Intensive surveys were conducted in the Lake Redding index area: ACID dam to slightly upstream of the City of Redding pump house (Figure 1). This is where the majority of winter-run spawning has been observed in the recent past. Surveys were also conducted in 1991 and 1992 in all areas upstream of this known to contain spawning gravel in order to gain a better understanding of winter-run chinook spawning (Vogel and Taylor 1987). Also surveyed during 1991 and 1992 were two areas below ACID (RM 296.6 and RM 298.3) near Turtle Bay, where water depth lessened the likelihood of spotting all redds by aerial survey.

Habitat Measurements

Water velocity and depth measurements were taken at a site being utilized by spawning fall chinook salmon (Market Street Bridge) and a site not being used (Turtle Bay West) in November 1991. During 1992, additional velocity and depth measurements were taken at the Redding Riffle site during winter chinook spawning season. This site had also been used by spawning salmon. No further habitat measurements were made in 1993.

Average water velocity and depth over these sites were measured by placing transects across the width of the gravel patch approximately every 100 ft. Water depth, water column velocity, and focal velocity were measured approximately every 10 ft along each transect. Water column velocity was measured at 20% and 80% of total depth and averaged, or in shallow water, at 60% of total depth from the surface. Focal velocities (at the fish's eye level above the riverbed) were estimated to be 0.5 ft above the substrate (Vogel 1982). All water velocity measurements were taken with a calibrated Swoffer® flow meter.

Both focal velocities and depth were compared with velocity measurements obtained by CDFG on winter-run chinook redds (Brown 1990). Comparisons were made using a two sample *t*-test (STSC, Inc. 1988). Focal velocities in CDFG's data were estimated at 0.6 ft off the bottom; it was assumed this difference in methods would not be significant and no adjustments were made.

Water velocity and depth measurements were also taken at recently constructed redds in the new gravel at Market Street Bridge in 1991 and Redding Riffle in 1991 and 1992. Measurements were taken just upstream or lateral to the redd to simulate hydraulic conditions present before the salmon began excavation.

Results

Gravel Movement Evaluation

Surveys of riverbed substrate confirmed the lack of available good spawning gravel in our study area prior to new gravel placement. The percentage of good spawning gravel was low at each site and, in general, decreased with river mile. Addition of gravel to the river improved spawning suitability in areas where gravel was graded below the waterline but did very little else for the first 2 years of the study. The majority of gravel at all sites remained where originally placed until high flow releases in 1993. However, some gravel movement did occur at the uppermost sites, Keswick and Salt Creek, throughout the study. This changed dramatically after spring flow releases in 1993. Photographs of each site, soon after initial gravel placement and following substantial gravel movement in 1993, are presented in Appendices A through G.

Keswick.—The Keswick site was not included in this study until 1991; therefore, no pre-placement survey was done. However, in 1991 new gravel from the dump site was found to have traveled across the channel and downstream approximately 125 ft. During 1992, good spawning substrate was found covering the stream channel for over 500 ft below the site (Appendix 2). After Spring 1993 flows, virtually no gravel remained on the bank at the Keswick site. Although surveys found 14% and 16% of the substrate in the fair and good spawning gravel categories, it appeared the majority of new gravel had moved further downstream. Tracer rock was recovered up to 3,200 ft downstream with poor (19%) and none (20%) making up most of the known substrate composition. Thirty percent of the area below Keswick was classified unknown due to poor visibility and swift currents (Figure 3; Appendix 3).

Salt Creek.—At the beginning of the study, the surveyed areas of Salt Creek site had the greatest percent (41%) of good spawning gravel available. The remaining substrate was categorized as 15% fair, 5% poor, and 39% none (Figure 4; Appendix 5). Throughout the study, gravel from this site moved progressively downstream. Two months after placement, new gravel was observed roughly 450 ft downstream of the dump site. During 1991, good spawning gravel was observed approximately 1,000 ft downstream of the placement site. Good spawning substrate was observed for over 1,200 ft downstream and a new build-up of gravel was seen at the bend in the river approximately 0.25 mi below the site during 1992 (Appendix 6). The combination of swift water velocities and poor visibility in 1993 made surveying the designated site difficult. Consequently, only 25% of the site was mapped. However, in the area surveyed, spawning substrate was found to be 0% good, 6% fair, 57% poor, and 37% none (Figure 4; Appendix 7). We assume this is representative of the entire site.

High water velocities explain the rapid movement of gravel through the Salt Creek site. This site is narrow and deep, resulting in high velocity flows. The north (right) bank, though adjacent to the gravel placement site, is shallow and dominated by bedrock during summer months. However, high winter flows which moved gravel out of the placement site also produced velocites through the north bank which made gravel retention impossible.

Diestelhorst.—In-depth substrate maps developed pre-placement in 1990 and post-high flows in 1993 revealed the amount of good spawning substrate present increased from 31% to 34% during the study period. Substrate classified as fair more than doubled from 17% to 43%; poor decreased from 31% to 20%; and none also decreased from 9% to 3%. Weed growth obscured a substantial amount of substrate in 1990. This lead to 12% of the area being classified as unknown. In 1993, none of the area was obscured by weed growth (Figure 5; Appendix 11). Initial gravel placement of approximately 1,200 yd^3 was mapped in 1990 (Appendix 10). No gravel movement was noted at Distelhorst during 1990, 1991, or 1992.

Market Street Bridge.—Amounts of good and fair spawning substrate found at the Market Street Bridge site in 1993 (12% and 19%) had changed little from the pre-placement surveys (13% and15%). The majority of substrate was classified as poor (58%), more than double the pre-placement amount (24%); 11% of the area was classified as none; and no area was classified unknown (Figure 6; Appendix 15). In 1990, none constituted 45% of the area surveyed; and 3% of this site was classified unknown. Roughly 11,000 yd^3 of spawning-sized gravel was placed at this site in 1990 (Appendix 14). No gravel movement was observed at this site in 1991 and only slight downstream movement was observed during 1992.

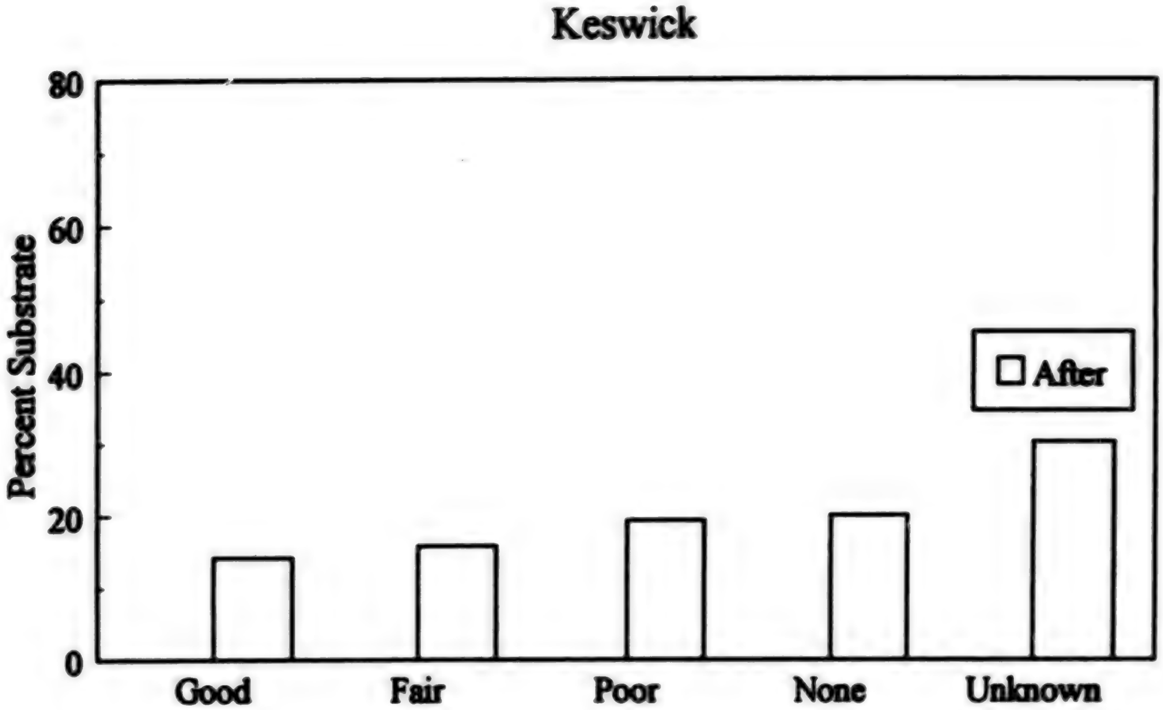

Figure 3.-Percentages of substrate categories found at Keswick gravel restoration site in 1993.

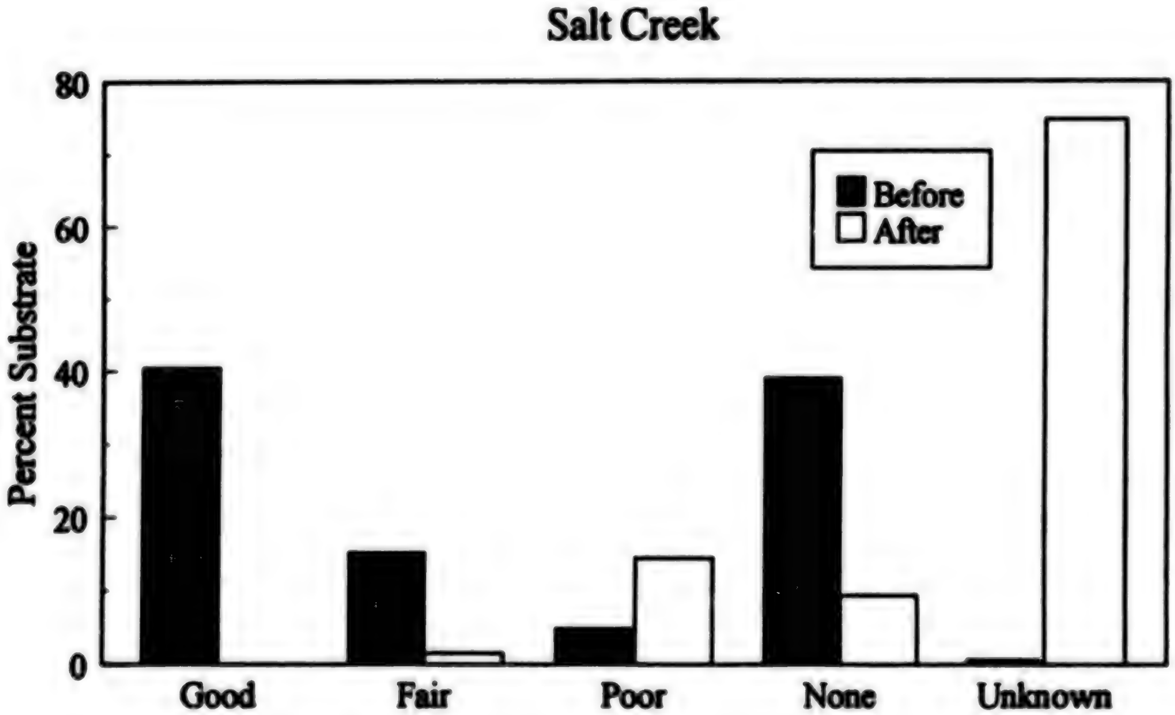

Figure 4.-Percentage of good, fair, poor, and none spawning substrate observed at the Salt Creek gravel restoration site before (1990) and after (1993) gravel placement. Areas not surveyed in 1993 were not included.

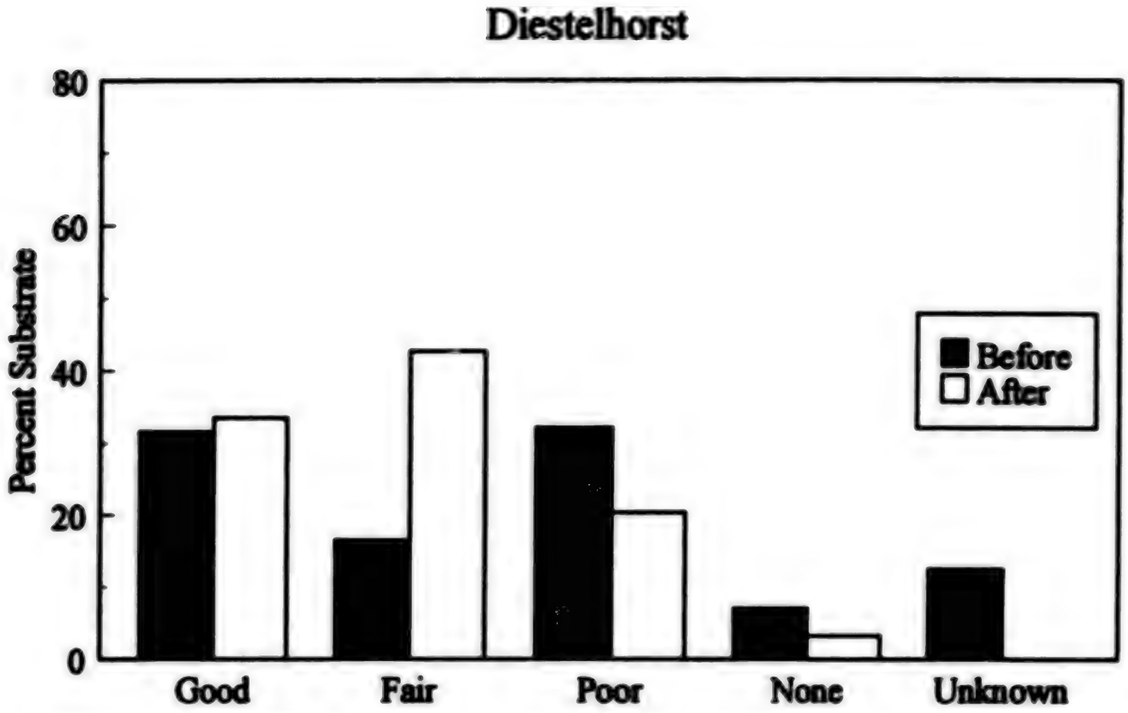

Figure 5.-Percentage of good, fair, poor, none, and unknown spawning substrate observed at the Diestelhorst gravel restoration site before (1990) and after (1993) gravel placement..

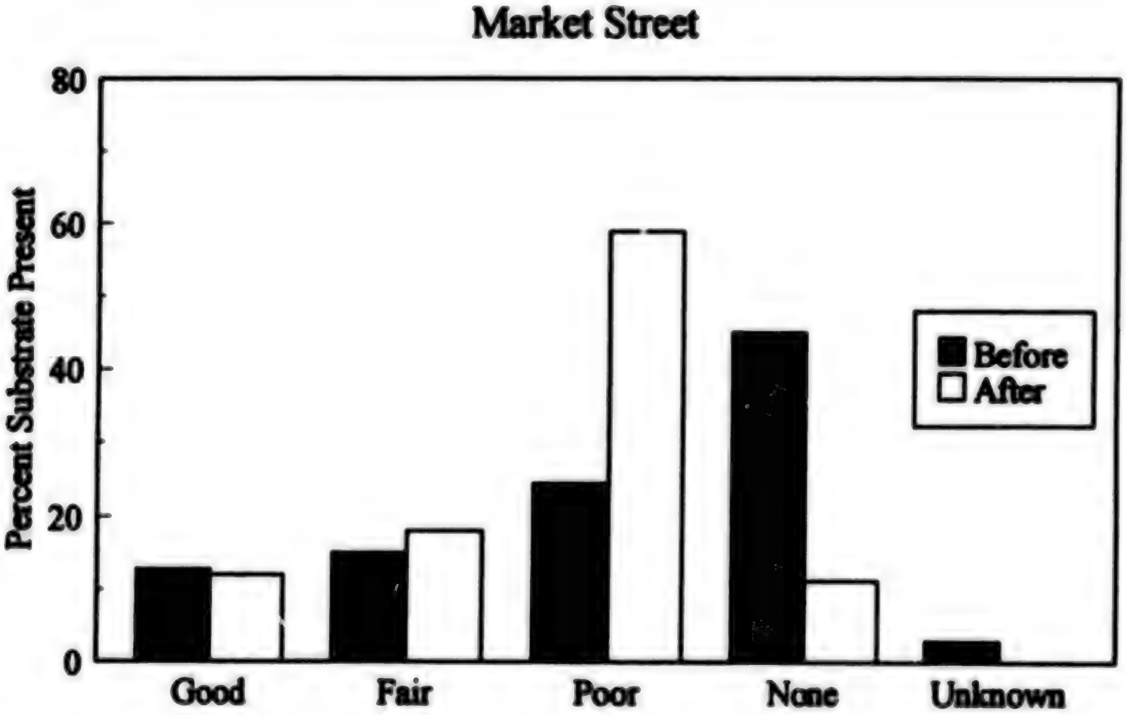

Figure 6.-Percentage of good, fair, poor, none, and unknown spawning substrate observed at the Market Street bridge gravel restoration site, before (1990) and after (1993) gravel placement.

Redding Riffle.—Fair (50%) and poor (33%) substrate increased at the Redding Riffle site over pre-placement estimates (13% fair, 25% poor) while good (16%) and none (1%) decreased during the same period (13% good, 38% none; Figure 7; Appendix 17). Over 12,500 yd^3 of gravel was placed here in 1990 (Appendix 18). No gravel movement was observed here in 1991; only slight downstream movement of gravel occurred in 1992. Tracer rock was found at this site, presumably originating from the Market Street Bridge site (0.1 mi upstream).

Shea Levee.—Post-gravel placement mapping at Shea Levee conducted in November 1993 revealed an increase in usable spawning substrate at this site (Figure 8; Appendix 22). Shea Levee had the smallest percent of good spawning gravel (8.0%) at the beginning of this study. Fair spawning gravel constituted 18% of the substrate at this site. Poor and none categories made up 69% and 4% of the available substrate. Less than 1% was categorized as unknown. Gravel was piled on the east bank of the river, where it remained until spring 1993. Good spawning substrate increased to 23%; fair substrate increased to 37%; areas of both poor and no spawning gravel decreased (37% and 0%). Unknown substrate comprised 3% of available substrate in 1993.

ACID to Keswick Dams.—Substrate from ACID Dam to Keswick Dam was classified as 24% good, 25% fair, 15% poor, and 14% none (Figure 9; Appendix 26). Approximately 23% of this section of river was not observed due to difficulties caused by swift currents and poor visibility.

Gravel Utilization

Redd construction was observed at all graded gravel sites with the exception of Turtle Bay West. Redding Riffle and Market Street Bridge sites were used considerably by fall-run chinook salmon in 1991. Of the 2,033 fall chinook redds counted above Red Bluff Diversion Dam (RBDD; RM 243) in the upper Sacramento River during 1991, 190 (9%) were seen in new gravel (Frank Fisher, CDFG, Red Bluff, unpublished data, 1991).

During 1992, only a few winter-run chinook spawners were observed utilizing the Redding Riffle gravel. No fall-run spawners were noted spawning in the new gravel. Spawning activity was noted in areas slightly downstream of the Salt Creek dump site. Redistribution of gravel by high flows in 1993 made it impossible to differentiate new gravel from gravel in the river prior to this study. Therefore, we were unable to document spawning activity specifically in new gravel.

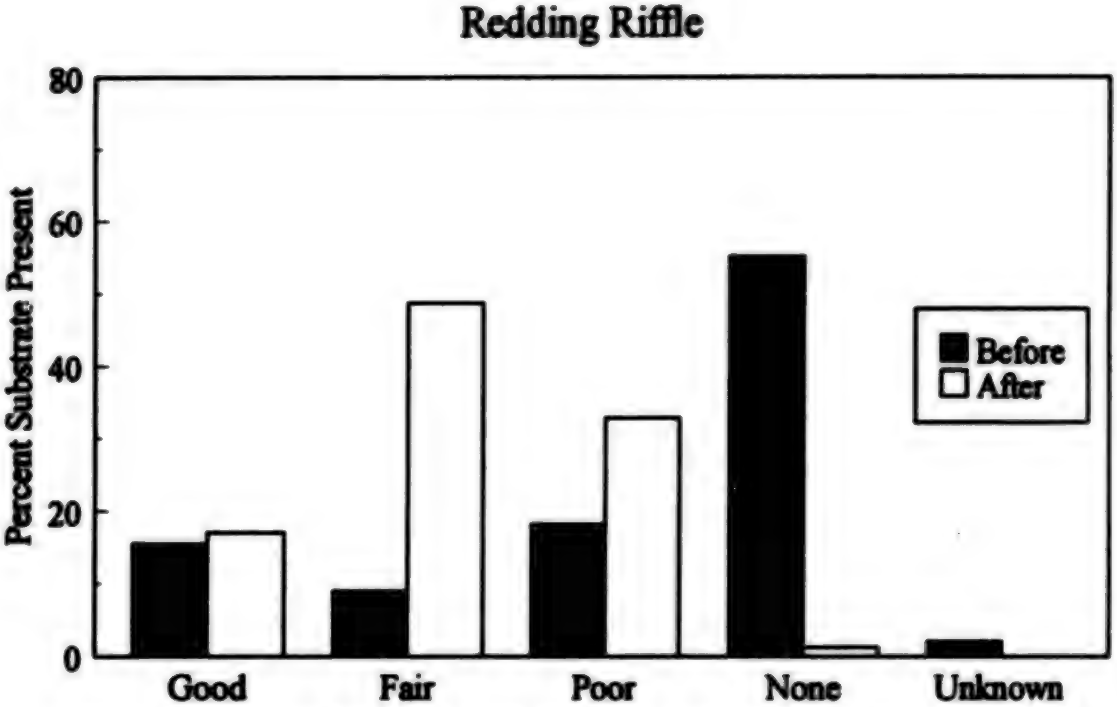

Figure 7.-Percentage of good, fair, poor, none, and unknown spawning substrate observed at the Redding Riffle gravel restoration site, before (1990) and after (1993) gravel placement.

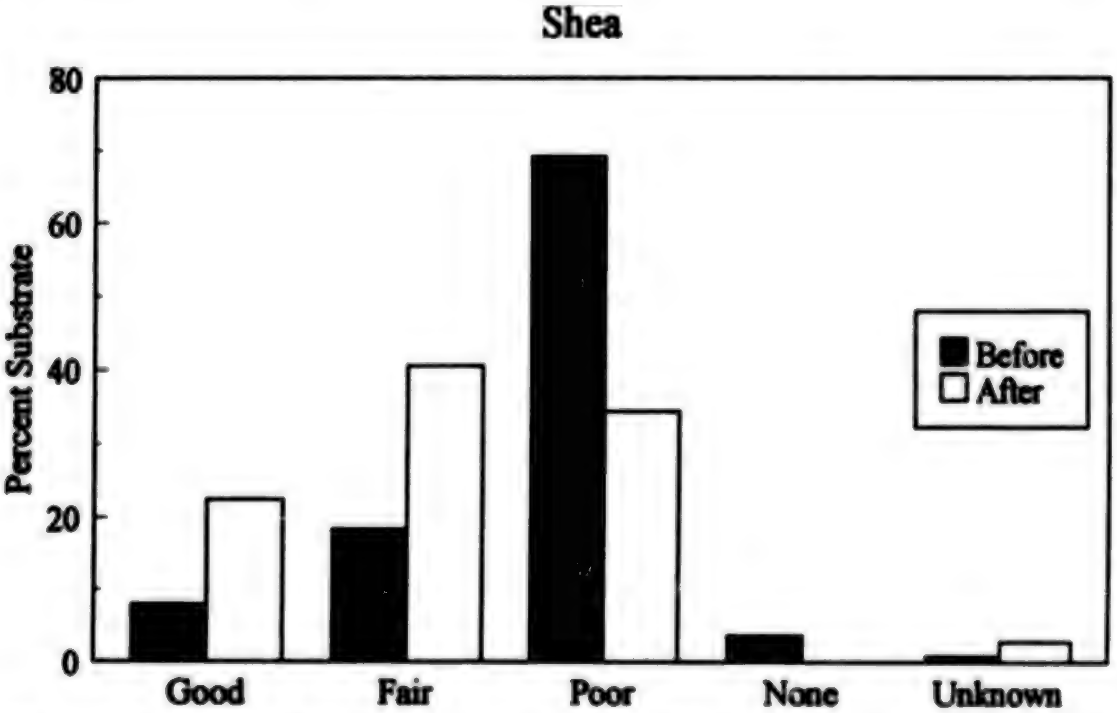

Figure 8.-Percentage of good, fair, poor, none, and unknown spawning substrate observed at the Shea Levee gravel restoration site before (1990) and after (1993) gravel placement.

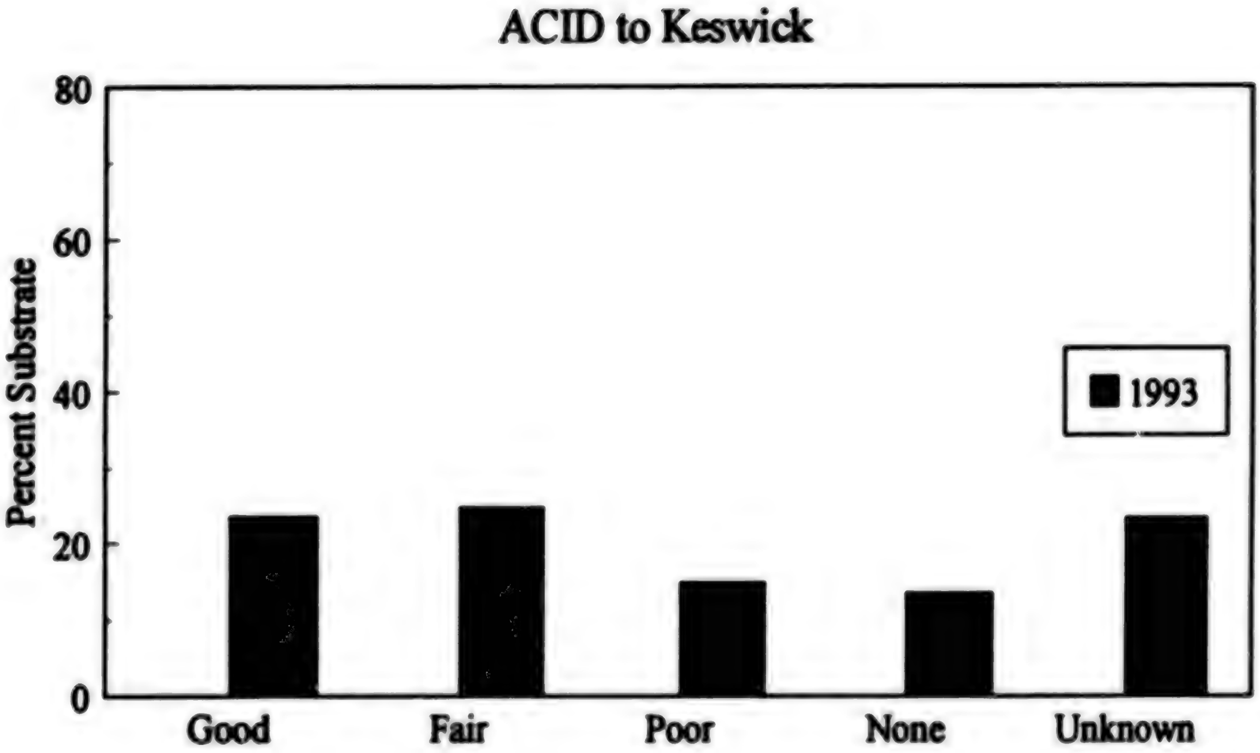

Figure 9.-Percentage of good, fair, poor, none, and unknown spawning substrate observed between the Anderson-Cottonwood Irrigation District and Keswick dams in July 1993. Unknown areas were not surveyed because of swift water currents.

Winter-Run Chinook Salmon Redd Surveys

Winter-run chinook redds seen by SCUBA techniques have declined drastically since counts began in 1987 (Appendices 27 through 33). Counts in the index area have decreased approximately 96% from 1987 to 1993 (Figure 10). Likewise, winter run chinook redds observed from ACID to Keswick dams decreased over 97% from 1987 to 1993 (Figure 10). Several redds, including 39 winter-run chinook redds, were counted in the 2 sites surveyed below ACID in 1992. This number declined to only 3 in 1993 (Table 2; Appendix 32)

Table 2.—Number of winter-run chinook salmon redds counted in the Turtle Bay area of the Sacramento River using SCUBA techniques, 1992 and 1993.

Site	1992	1993
northwest of Redding Riffle	9	3
Turtle Bay upstream of Hwy 44 bridge	30	0

Habitat Measurements

Velocity and depth measurements over gravel at Market Street Bridge and Turtle Bay West sites differed noticeably in September 1991 (Figure 11). Median depth at Turtle Bay West (1.8 ft) was about twice that of Market Street Bridge (1.0 ft). Both median water column velocity (1.44 ft/s) and median focal velocity (1.34 ft/s) at Turtle Bay West were approximately half what they were at Market Street Bridge (2.54 ft/s and 3.01 ft/s, respectively). Keswick flow releases were at approximately 4,200 ft^3/s.

Depths and velocities of values measured at both Market Street Bridge and Turtle Bay West gravel sites were within the range selected by fall-run chinook salmon in northern California (Vogel 1982, Hampton 1988). Depth ranged from 1 to 2 ft; water column and focal velocities ranged 0.95 to 3.60 ft/s and 1.03 to 4.05 ft/s, respectively.

Water column velocity measured over Redding Riffle in 1992 averaged 3.11 ft^3/s and ranged from 0.0 to 5.55 ft^3/s. Focal point velocities over Redding Riffle gravel during the 1992 winter chinook spawning season (with Keswick releases at about 7,100 ft^3/s) averaged 2.93 ft^3/s and ranged from 0.00 to 4.91 ft^3/s. Water depths over Redding Riffle gravel averaged 1.62 ft and ranged from 0.0 ft to 3.5 ft.

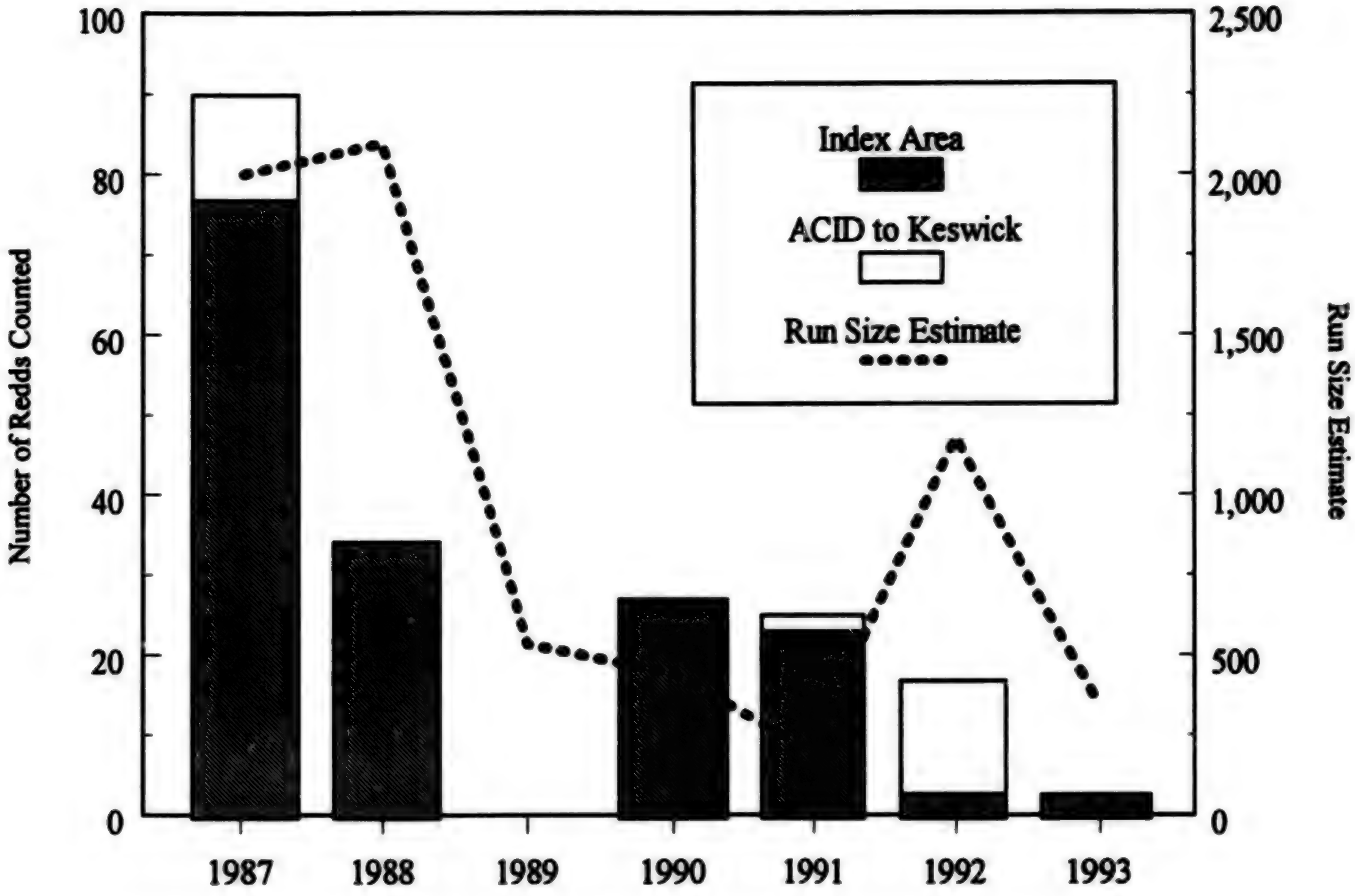

Figure 10.- Number of winter-run chinook salmon redds counted by SCUBA techniques between the Anderson-Cottonwood Irrigation District (ACID) diversion and Keswick dams in the upper Sacramento River. Counts in 1988 and 1990 were conducted only in a 0.6 mi index area from ACID Dam upstream to the water intake for the City of Redding. No counts were made in 1989 due to poor visibility.

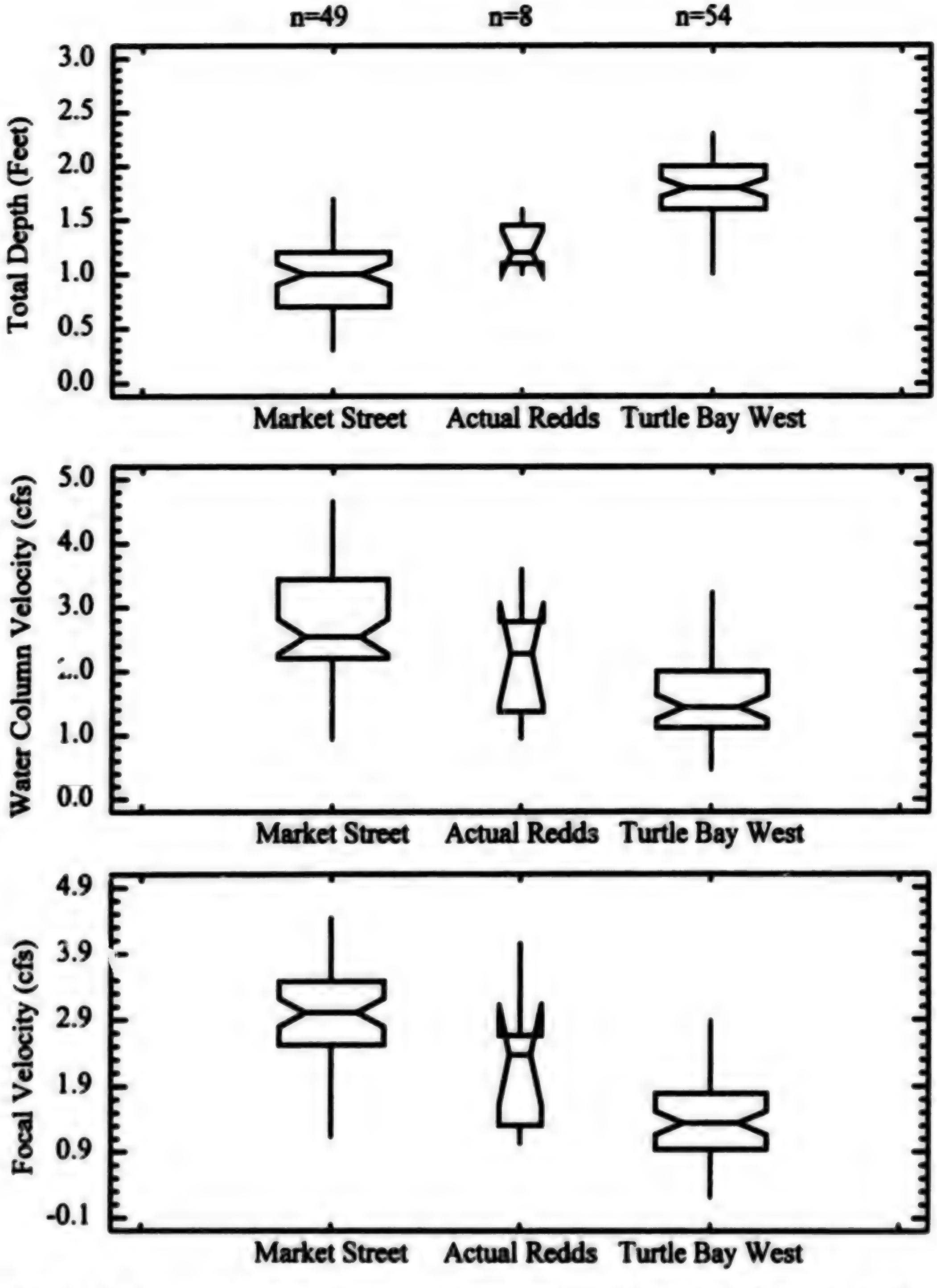

Figure 11.-Total depth, water column velocity, and focal velocity for gravel sites at Market Street bridge and Turtle Bay West sites, September 1991. Each boxplot is a graphical representation of data distribution. The central box covers the middle 50% of the data values, with "whiskers" depicting the range of data values, and the midline represents the median. Notches represent the 95% confidence interval about the median. The width of the box is proportional to the square root of the number of observations in each data set (STSC, Inc. 1988).

Discussion

River Flows in the Upper Sacramento River

During the first three years of this study (1990, 1991, and 1992), California was suffering from the last years of a seven year drought. Flows released to the Sacramento River from Keswick Dam were below the average of the preceding 26 years (Figure 12). Spring rains in March 1992 led to Keswick releases of approximately 20,000 ft^3/s. Although these flows were the highest releases occurring since gravel placement in 1990, they were very short in duration (2 days). In 1993, spring rains in March led to high flow releases in the upper Sacramento River. Releases from Keswick Dam peaked at approximately 50,000 ft^3/s and high flows were maintained for over two weeks period of time.

Gravel Movement Evaluation

Graded sites.—For the majority of the study gravel placed below the low-water line at graded sites remained where initially placed. Keswick releases of approximately 20,000 ft^3/s in 1992 caused only a slight downstream shift of gravel at Diestelhorst, Market Street Bridge, and Redding Riffle sites. These flows had no discernable effect on either of the Turtle Bay sites. However, high flow releases from Keswick in 1993 did substantially move gravel downstream at each site.

Comparison of substrate maps in 1990 and 1993 showed nearly equivalent amounts of good spawning substrate at Diestelhorst, Market Street Bridge, and Redding Riffle sites before the addition of gravel and after the high flow event of 1993. Likewise, no change in the percent of fair substrate was seen at the Market Street Bridge site. Fair spawning substrate did, however, increase substantially at both the Diestelhorst and Redding Riffle sites. This indicates high flows moved a substantial amount of gravel out of these sites. The majority of spawning gravel was completely moved out of the Market Street Bridge site. Presence of some tracer rock at the Redding Riffle site confirms at least some of the gravel present here originated at the Market Street Bridge site. Aerial surveys suggest that, although gravel moved out of our study sites, it did remain in the river channel where it was available to spawners. No evaluation of areas where gravel was redistributed downstream was done, but it is assumed new spawning habitat was created.

Dump sites.—Gravel placed at both the Keswick and Salt Creek sites moved downstream each year of the study. Although flows remained low throughout the initial years of the study, gravel still progressed from these sites downstream. Below the Salt Creek site new spawning gravel was made available to adult chinook salmon almost immediately. The high flows of 1993 removed most of the gravel piles from both Keswick and Salt Creeks sites.

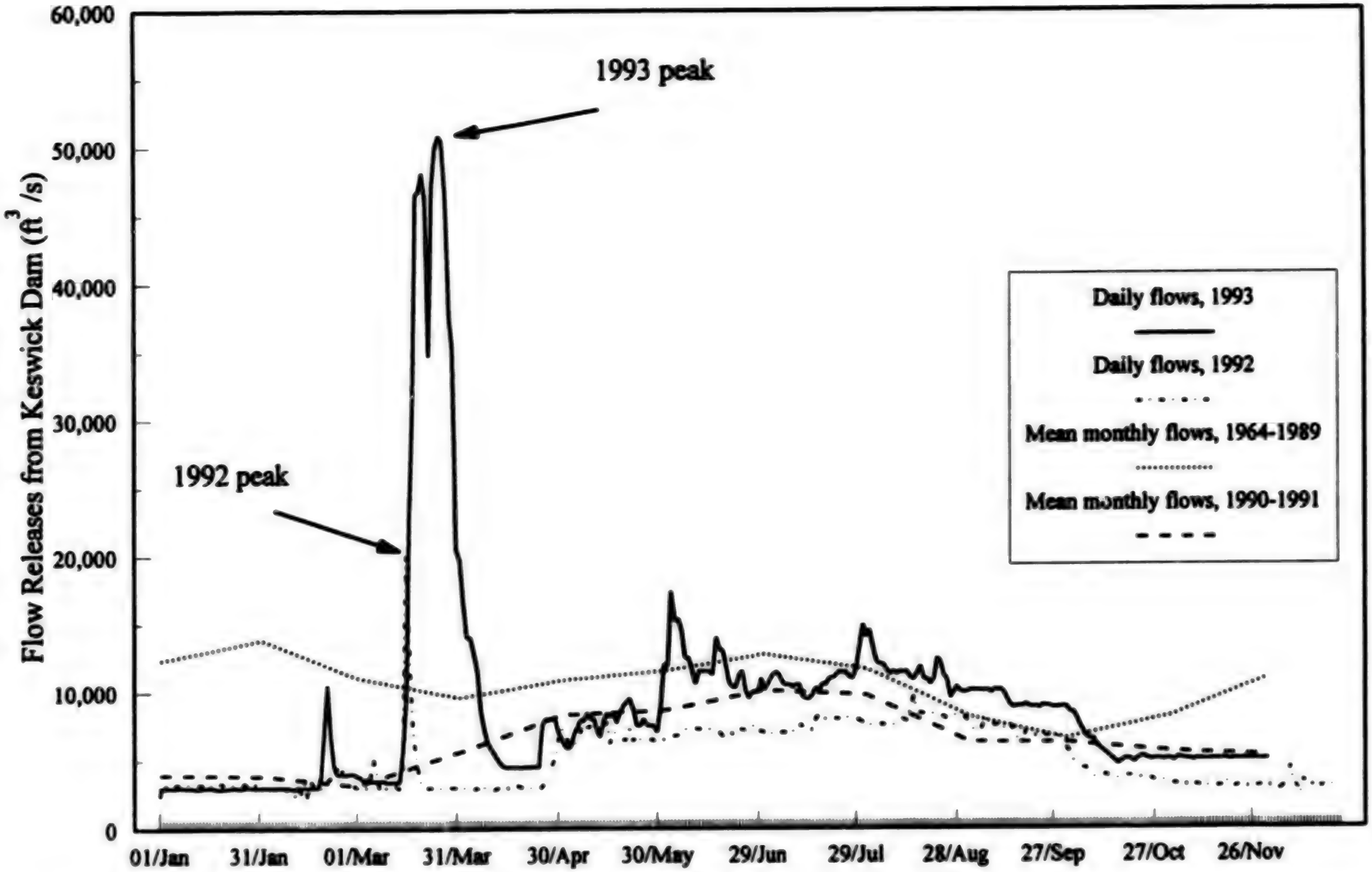

Figure 12.- Flow releases from Keswick Dam, 1964-1993. Mean monthly flows for 1964-1989 represent the long-term average. Mean monthly flows for 1990-1991 are releases which have occurred since gravel placement in 1990. Daily flows in 1992 peaked higher than had previously occurred during the project study period. However, they quickly decreased to below the long term average. Daily flows in 1993 demonstrate the much greater flows which occurred in spring 1993.

Like the graded sites, dump sites further downriver showed little change until the high flow releases early in 1993. Large amounts of gravel were sloughed off banks at both Tobiasson and Shea sites during Keswick releases of 50,000 ft^3/s. Substrate mapping at Shea revealed the amount of good and fair spawning substrate present more than doubled.

Anderson-Cottonwood Irrigation Diversion Dam to Keswick Dam.—An overall increase in spawning substrate present was noted in this reach of river when compared with that found by Vogel and Taylor (1987; Figure 13; Appendix 26). If we assume the worst and believe the entire area unsurveyed in 1993 (24%) was in the none category, the percentage of good and fair spawning substrate present still shows an increase over 1987 results from 33% to 49% of the riverbed. Undoubtedly, good and fair spawning substrate are available in areas we were unable to survey and the actual increase in suitable spawning substrate is greater than that represented here. Visual inspection of our and Vogel's and Taylor's maps (1987) suggests the greatest increase in spawning substrate occurred in the section of river corresponding to Vogel's and Taylor's Map 3 (RM 299.35 through RM 300.03; Appendix 26d through 26g). Good spawning substrate increased from 10.8% to 36.0% (Figure 14). This increase in spawning gravel has been a result of adding gravel to the system, most likely at Salt Creek. No other gravel sources of the magnitude required to cause these increases exist in this stretch of the river.

Large amounts of spawning gravel were moved out of all study sites during high flows in early 1993. Even so, with the exception of Salt Creek, enough new spawning substrate remained at all sites to improve conditions, at least slightly, over what was present during the 1990 surveys (Figure 15). When the 1993 Salt Creek survey data is compared with data obtained in 1987 (Vogel and Taylor 1987), it too shows a substantial improvement. Vogel and Taylor found 95% of the Salt Creek site had no spawning substrate present. The high percentage of good and fair spawning substrate found at this site in 1990 was most likely from gravel addition which occurred here in 1988.

Gravel Utilization

During 1991, adult fall-run spawners made considerable use of new gravel at the Market Street Bridge and Redding Riffle sites. However, chinook spawners made very little use of these areas during 1992 and 1993. Only a few winter-run chinook were seen spawning at the Redding Riffle gravel site throughout the study. This is, however, more likely attributable to low adult escapement rather than unsuitable conditions. Keswick flows were reduced prior to fall chinook peak spawning in 1992 and 1993; this lowered water velocities and depths, decreasing the value of these areas for spawning.

Utilization of new gravel in 1993 by adult chinook salmon is not directly documented, gravel moved considerably to the beginning of spawning activity and it was no longer possible to identify all "new" gravel. However, spawning activity was noted below Salt Creek and in the Redding Riffle area. It is likely at least some of this gravel utilized for spawning was from the new deposits.

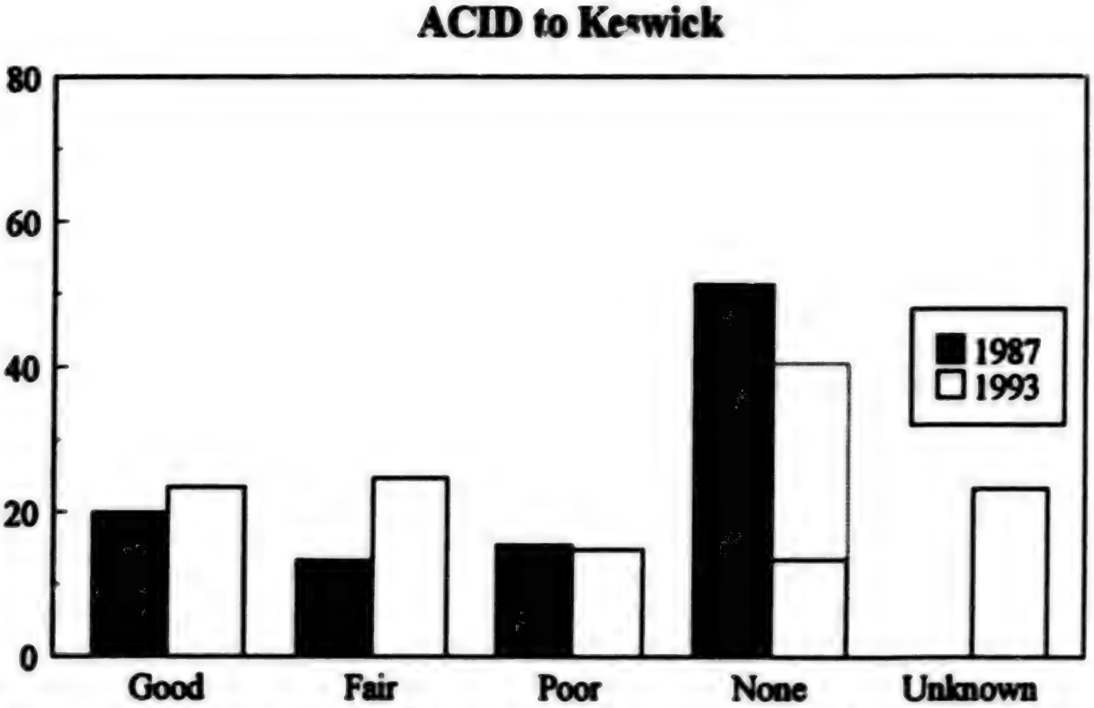

Figure 13.-Percentage of good, fair, poor, none, and unknown spawning substrate observed between the Anderson-Cottonwood Irrigation District and Keswick dams by Vogel and Taylor (1987) and by our office in July 1993. Dashed bar over none represents total of none and unknown combined.

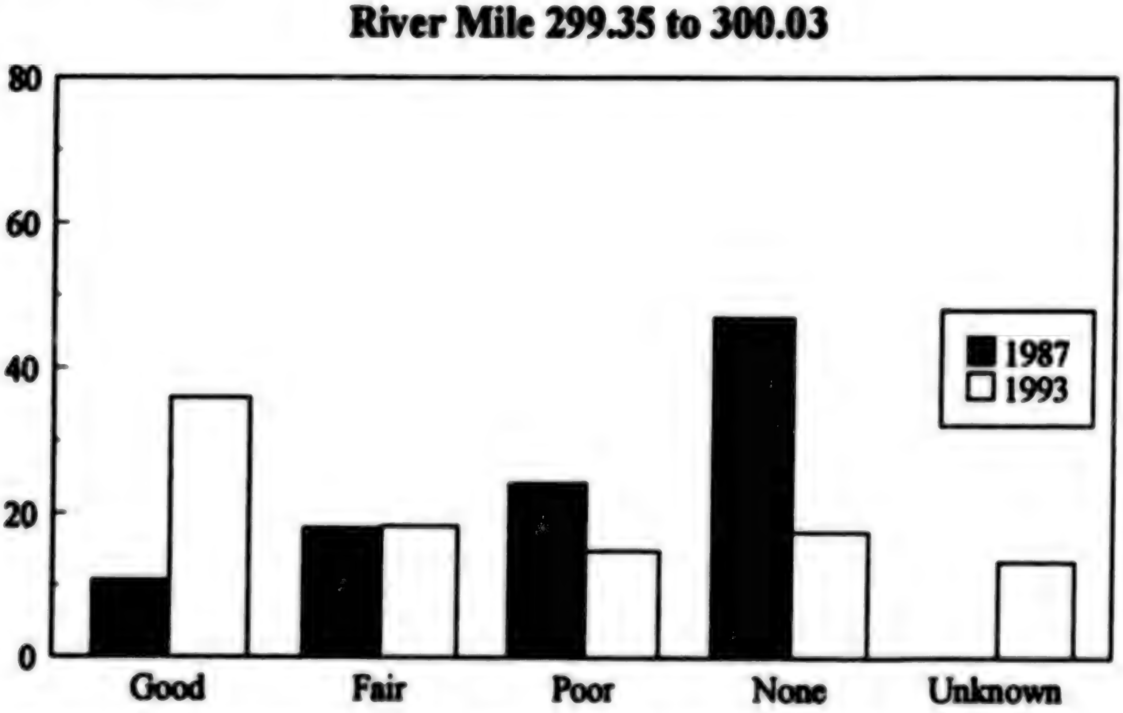

Figure 14.-Percentage of good, fair, poor, none, and unknown spawning substrate found from RM 299.35 to RM 300.03 by Vogel and Taylor (1987) and our office after high river flows in 1993. A substantial increase in the amount of good spawning substrate present occurred.

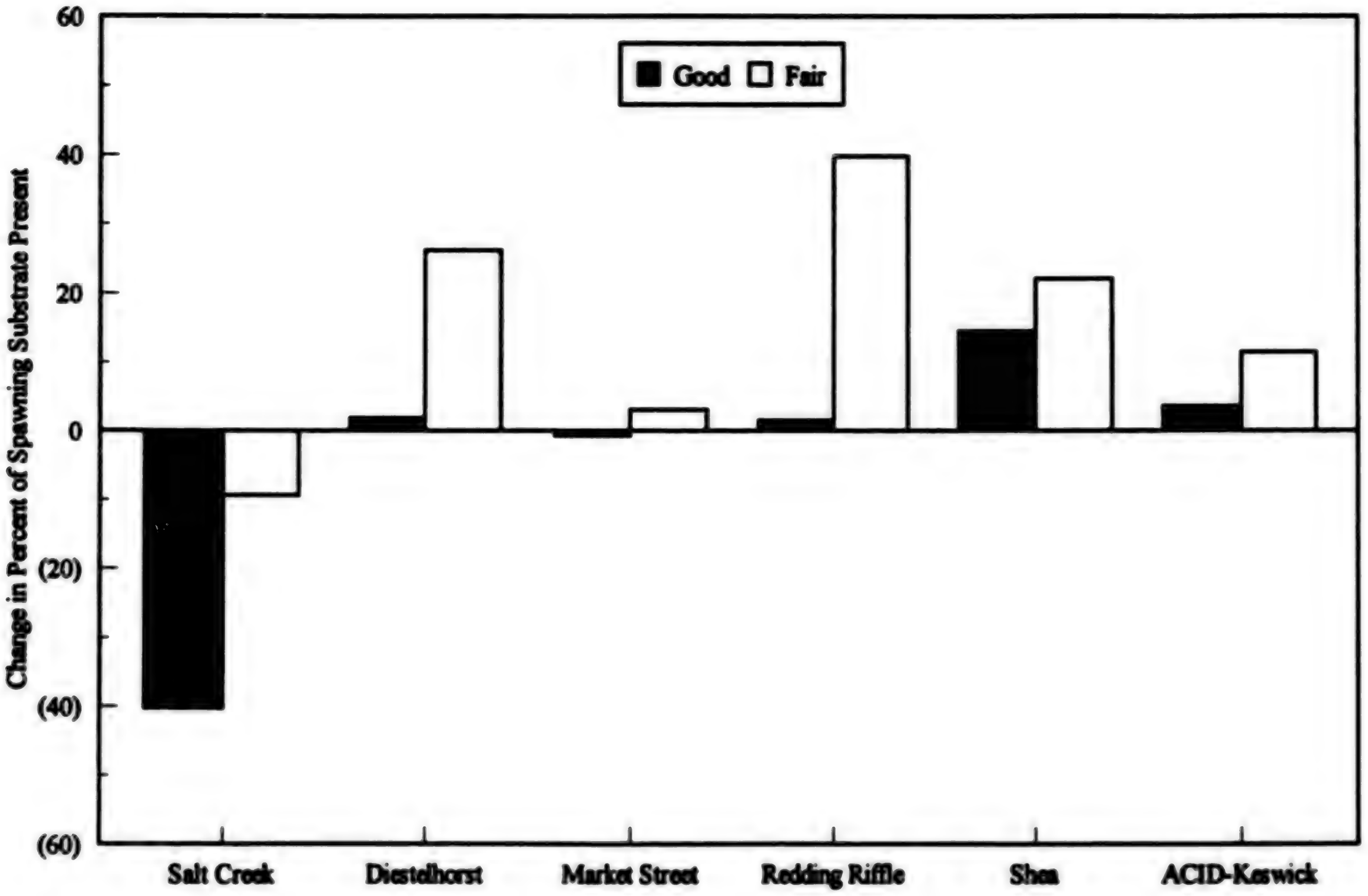

Figure 15-Change in percent of good and fair spawning gravel substrate found at each site and from the Anderson-Cottonwood Irrigation District to Keswick dams. Bars represent changes occurring at each site between mapping done pre-gravel placement in 1990 and post-gravel placement in 1993. The ACID - Keswick bar represents changes between results obtained by Vogel and Taylor (1987) and our office in 1993.

Winter-Run Chinook Salmon Redd Surveys

Numbers of winter-run chinook spawning in the upper Sacramento River continue to decline. Although SCUBA surveys do not yield exact counts of redds, we feel confident the majority were seen. These counts can be considered a measure of trend, documenting the precipitous decline of winter-run chinook salmon in the upper Sacramento River. However, factors other than run size must also be contributing to the lack of spawning in the index reach. Although estimated run size for 1992 was low (1,180), it was considerably higher than the previous three years (Figure 10). Habitat changes, accessibility, and removal of adults from the area to Coleman NFH affect numbers spawning in the area.

Habitat changes.—The Sacramento River Valley has weathered a seven year drought. Resultant changes in flow patterns, particularly a lack of high winter and spring flows, have contributed to habitat changes in the index area. Siltation and weed growth in the Lake Redding area increased noticeably over the years the redd surveys were conducted until 1993. This is most likely attributable to a lack of high flow releases from Keswick and increased fine sediment loading from Middle Creek watershed. Increased siltation and weed growth in the Lake Redding area from 1990 through 1992 appears to have decreased the area's value as spawning habitat during that time. However, the high flow releases during 1993 flushed the majority of siltation further downstream. Substrate surveys in 1993 found no areas in this stretch of river obscured by weed growth.

Accessibility.—Dam board placement at ACID severely restricts chinook access to the section of the Sacramento River above the dam. Boards are placed late March to mid-April and removed late October to early November (Appendix 34). Limiting fish access to areas of the Sacramento River above ACID would reduce the number of redds seen during SCUBA surveys in the index area.

Removal of Adults From the Area. Some winter-run chinook salmon adults are removed from the upper Sacramento River before spawning. For the past 5 years, Coleman NFH has operated the fish trap at Keswick Dam as part of the winter-run artificial propagation program (USFWS 1991). In an effort to assist recovery of the winter-run chinook salmon, Coleman NFH captures wild broodstock from the river to use as an egg source. Although fish captured at the Keswick trap in excess of program needs are returned to the river, they are sometimes returned below the ACID dam (Figure 16). After dam boards are placed at this diversion chinook spawners likely are unable to pass further upstream. This practice reduces the number of chinook spawners in the reach of river we are surveying and may reduce the number spawning in the Lake Redding area.

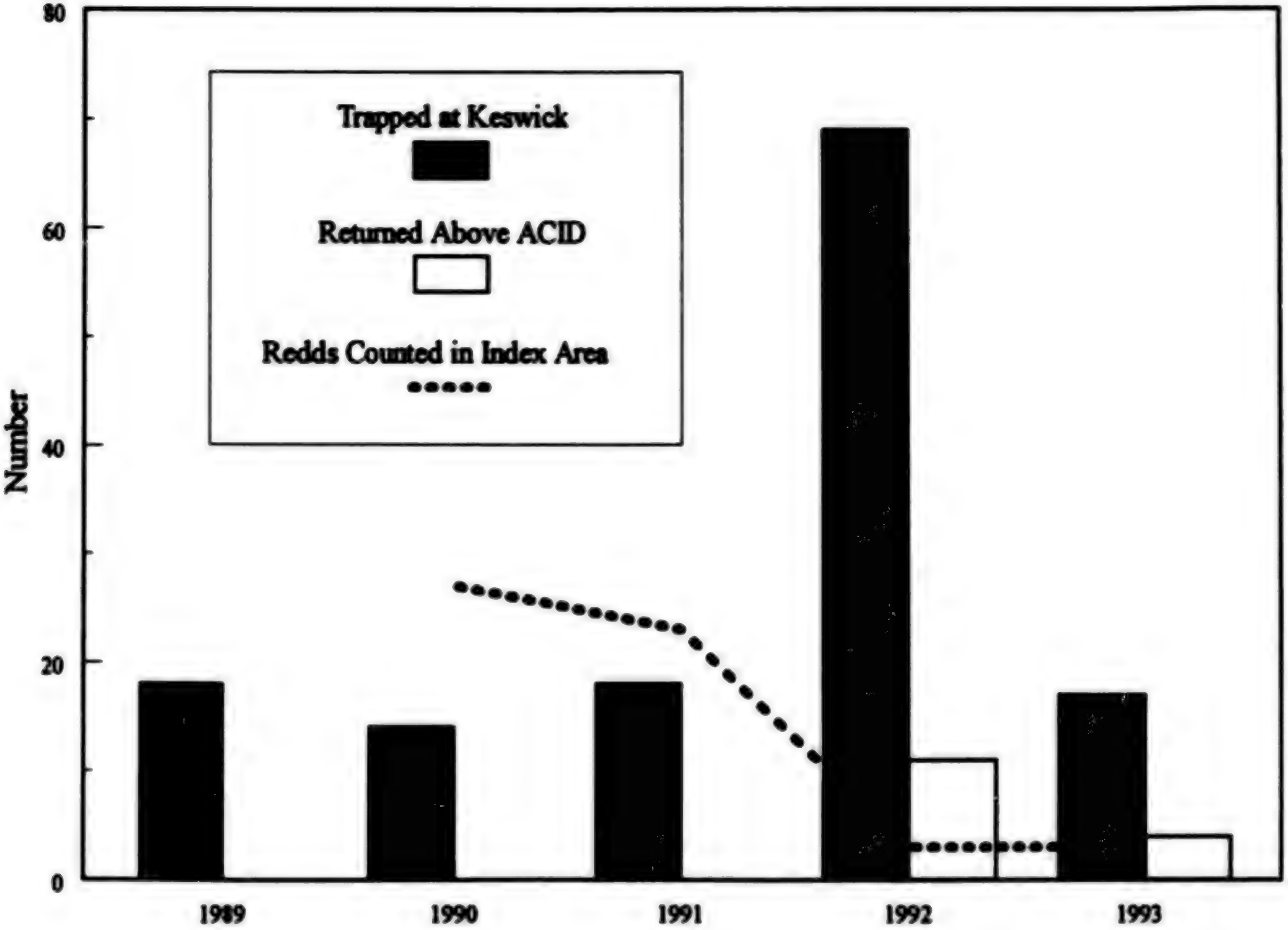

Figure 16.-Number of adult winter chinook salmon captured at Keswick Dam fish trap, number of those fish returned to the upper Sacramento River, and number of redds counted in the lake Redding index area, 1989 - 1993.

Habitat Measurements

Water depth and velocity data collected in 1991, although incomplete, revealed significant differences between areas selected for spawning and unused gravel sites. Gravel areas selected for spawning were shallower with faster velocities than those not selected. However, location of these areas could also be a contributing factor. Redding Riffle and Market Street Bridge sites, the two most heavily used areas, are just below ACID dam. During fall chinook spawning, ACID dam gates are in place and access to areas of the river above this is limited. Turtle Bay West is over a mile downstream of ACID. The lack of spawning adults, even in the fall run of chinook salmon (the most abundant chinook in the system), makes it impossible to ascertain whether spawning gravel is unused because of inappropriate hydrologic conditions or gross underseeding of the area. However, observed depths and velocities at unused sites fall within range of other reported habitat preferences for fall chinook in northern California (Vogel 1982, Hampton 1988).

Although significant differences exist between mean focal velocities selected by winter-run chinook salmon reported by Brown (1990) and those found at Redding Riffle (*P*=0.03), ranges in velocities were very similar (Figure 17). Also, water depths available at the Redding site were significantly different than those chosen by winter-run chinook for spawning (*P*=0.00) but were within the range utilized (Figure 18). They were, however, at the low end of the range. This suggests habitat created in the Redding Riffle area by the addition of gravel is suitable, but perhaps marginal, for winter-run salmon, at flows present during the 1992 spawning season.

Conclusions and Recommendations

Conclusions

1. Even during low flow years, gravel added to the Sacramento River at the Keswick and Salt Creek restoration sites slowly redistributed downstream and across the river channel, increasing the amount of suitable spawning substrate available for chinook salmon.

2. During high flow years, gravel added to the upper Sacramento at the Keswick and Salt Creek sites moved downstream substantial distances, at least 3,200 ft and 4,800 ft, creating new spawning areas.

3. Although new gravel at Turtle Bay East, Market Street Bridge, Redding Riffle and downstream of Salt Creek has been utilized by spawning chinook salmon in the past, usage has been variable. These areas were unsuitable as spawning habitat for fall chinook in 1992 because of low flow releases from Keswick Dam. A few winter-run chinook have been seen spawning at the Redding Riffle site and below Salt Creek site.

4. Gravel dispersed into the river at Shea Levee during flows in excess of 50,000 ft^3/s from Kewsick Dam; however, we do not know precisely at what flows gravel started to move. Dispersed gravel increased good (23%) and fair (37%) substrates over baseline estimates.

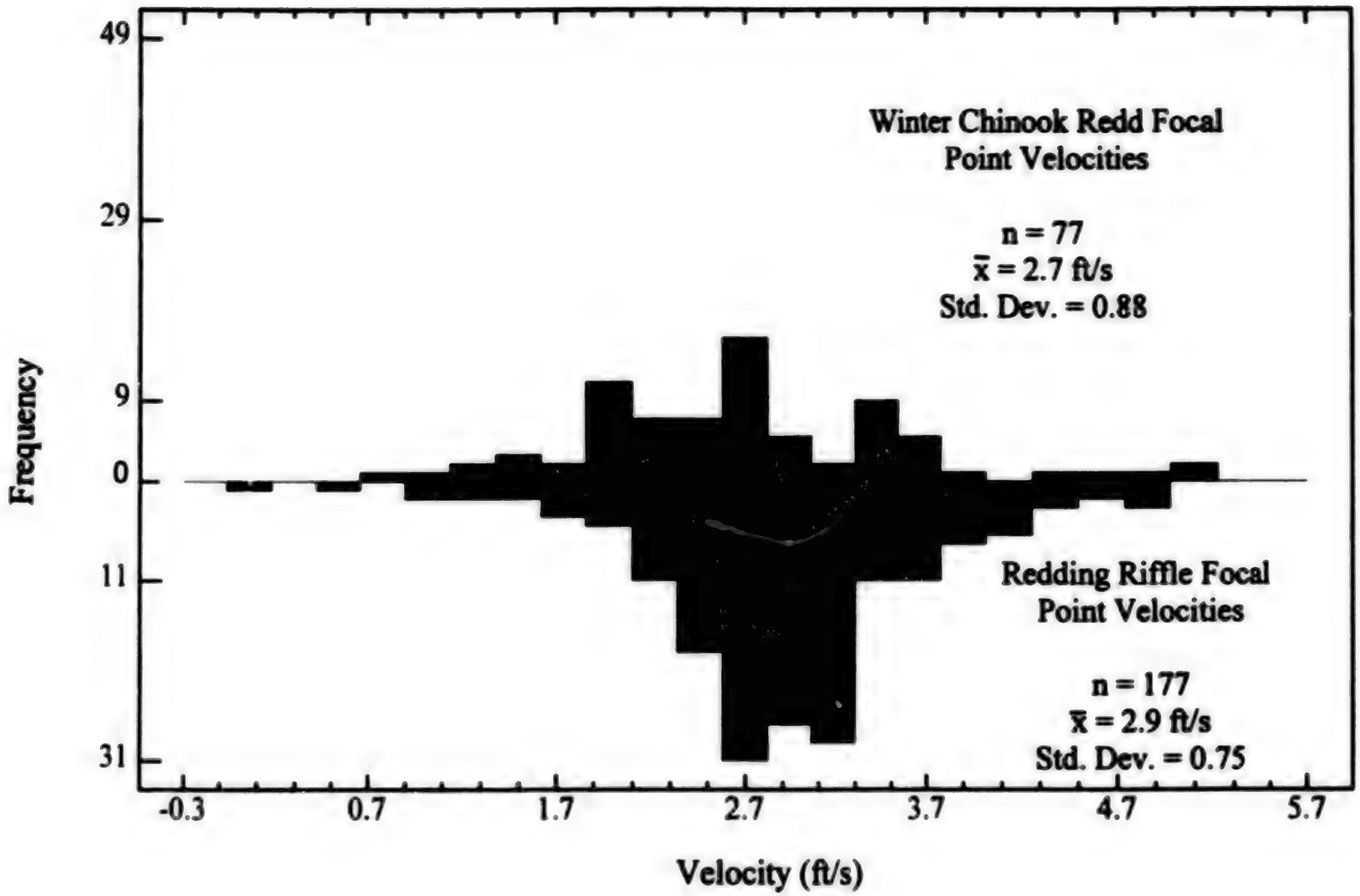

Figure 17.-Comparison of focal point velocities available at Redding Riffle gravel site and those chosen by winter chinook salmon during redd construction. Although significant differences exist between data sets (*P*=0.03), note the similar ranges.

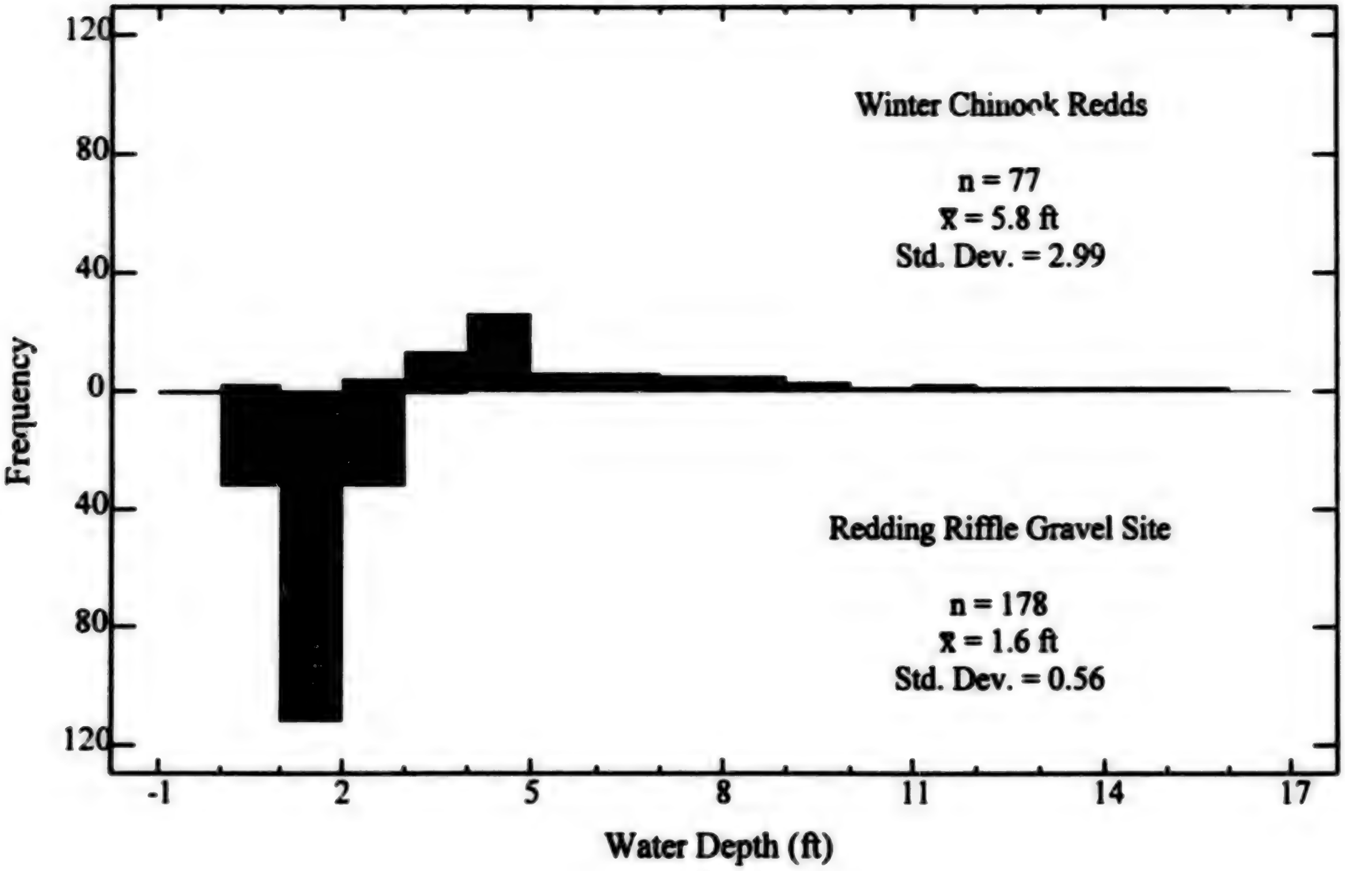

Figure 18.-Comparison of water column depths measured over Redding Riffle gravel during winter chinook spawning season and depths selected by winter chinook for redd construction.

5. Underwater SCUBA counts of winter-run chinook redds in the Lake Redding Index Area (RM 298.7 to RM 300.4) have declined 96% since they began in 1987.

6. Usefulness of the Lake Redding area of the Sacramento River as an index of winter chinook run strength is questionable. Water velocity, sedimentation and weed growth, which influence quality of spawning habitat, fluctuate with flow releases from Keswick Dam. Adult salmon access to the area is limited after installation of ACID Dam in May. Also, relocation of adults captured in the fish trap at Keswick Dam downstream of ACID Dam or to Coleman NFH affects the number of spawning adults in the Lake Redding area.

7. Appropriate water velocity and depth, along with suitable spawning substrate, are required to increase available spawning habitat, and are greatly affected by Keswick flow release levels.

Recommendations

1. Appropriately-sized gravel should continue to be added to the Sacramento River by stockpiling it on the bank and allowing it to semi-naturally accrete to the ecosystem during high flows. Recommended sites for stockpiling are Keswick (RM302), Salt Creek (301) and Shea Levee (RM 290).

2. Other sites should be explored for bank stockpiling to allow greater flexibility in placement.

3. Sedimentation in gravel beds can negate benefits of increasing the amount of gravel present. Sedimentation of new gravel beds should be monitored during low flow years to assess if flushing flows are required to maintain the quality of habitat created by this project.

4. The source of gravel used for this work should be carefully considered. Removing gravel from the Sacramento River or its tributaries, where it would have naturally recruited into the system near areas to be rehabilitated, will not accomplish the intended objective of increasing spawning habitat in the river.

5. Habitat quality should be monitored in the Lake Redding area. Sedimentation and weed growth observations in Lake Redding should be documented to determine if average flushing flows will maintain spawning conditions in this area.

6. Redd surveys using SCUBA techniques should continue opportunely. Surveys should focus in areas above and below ACID Dam where good spawning gravel is present and aerial survey methods are not effective. This information is useful for demonstrating use by spawning adults in new gravels introduced to the river. Additionally, redd surveys provide supportive evidence for estimates of run strength.

Acknowledgements

This report would not be possible without the competent assistance of several others. I would especially like to thank Rich Johnson for compiling review comments and editing the final draft. I would also like to gratefully acknowledge the assistance of past and present members of this office: Dave Vogel for project initiation, and Keith Marine for initial study design and project proposal. My appreciation to past and present members of our survey team: divers Jerry Big Eagle, Jim Smith, Rich Johnson, Scott Hamelberg, Dave Vogel, Keith Marine, Sven Johnson, Jon Raby, Jay Bigelow, Randy Rickert, and Dave Weigand; and crew members: Kurt Brown, Dwight Varela, Mary Whitfield, Garwin Yip, Teri Moore, and Keri Fitzgerald. Teri Moore and Angie Taylor completed many hours of tedious map work; and Jim Smith, Rich Johnson, Scott Hamelberg, and Jay Bigelow of USFWS and Ralph Hinton of the California Department of Water Resources critically reviewed the report. Randy Brown, USFWS Lewiston Field Office, and Chris Mobley and Dante Maragon, U. S. National Marine Fisheries Service, Santa Rosa, California also assisted with diving.

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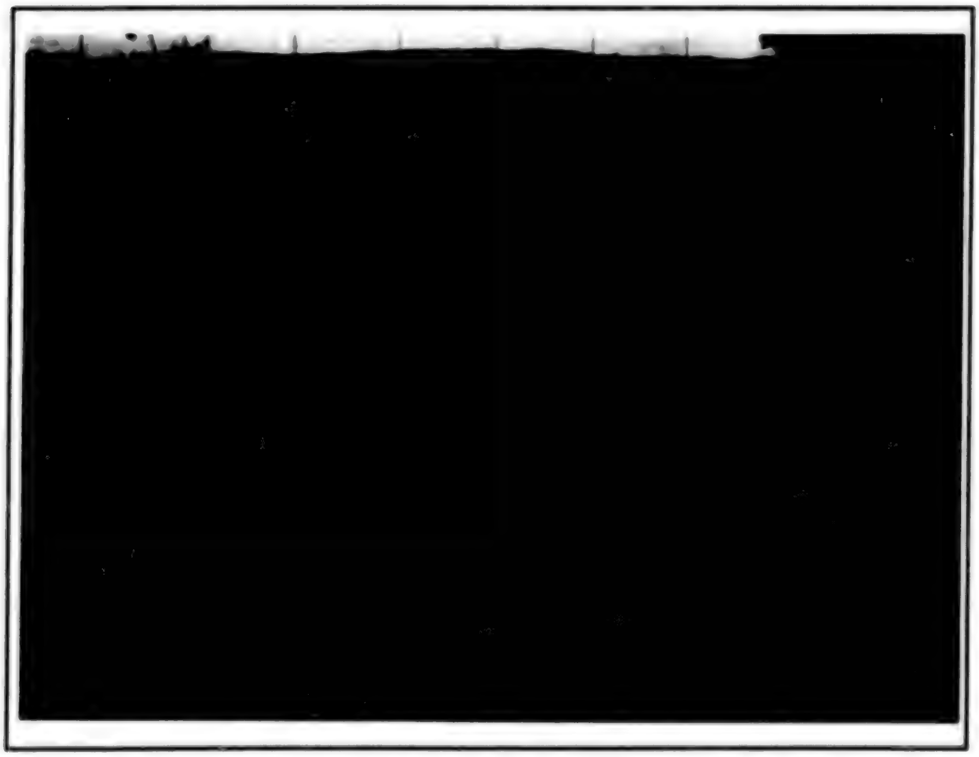
Appendices

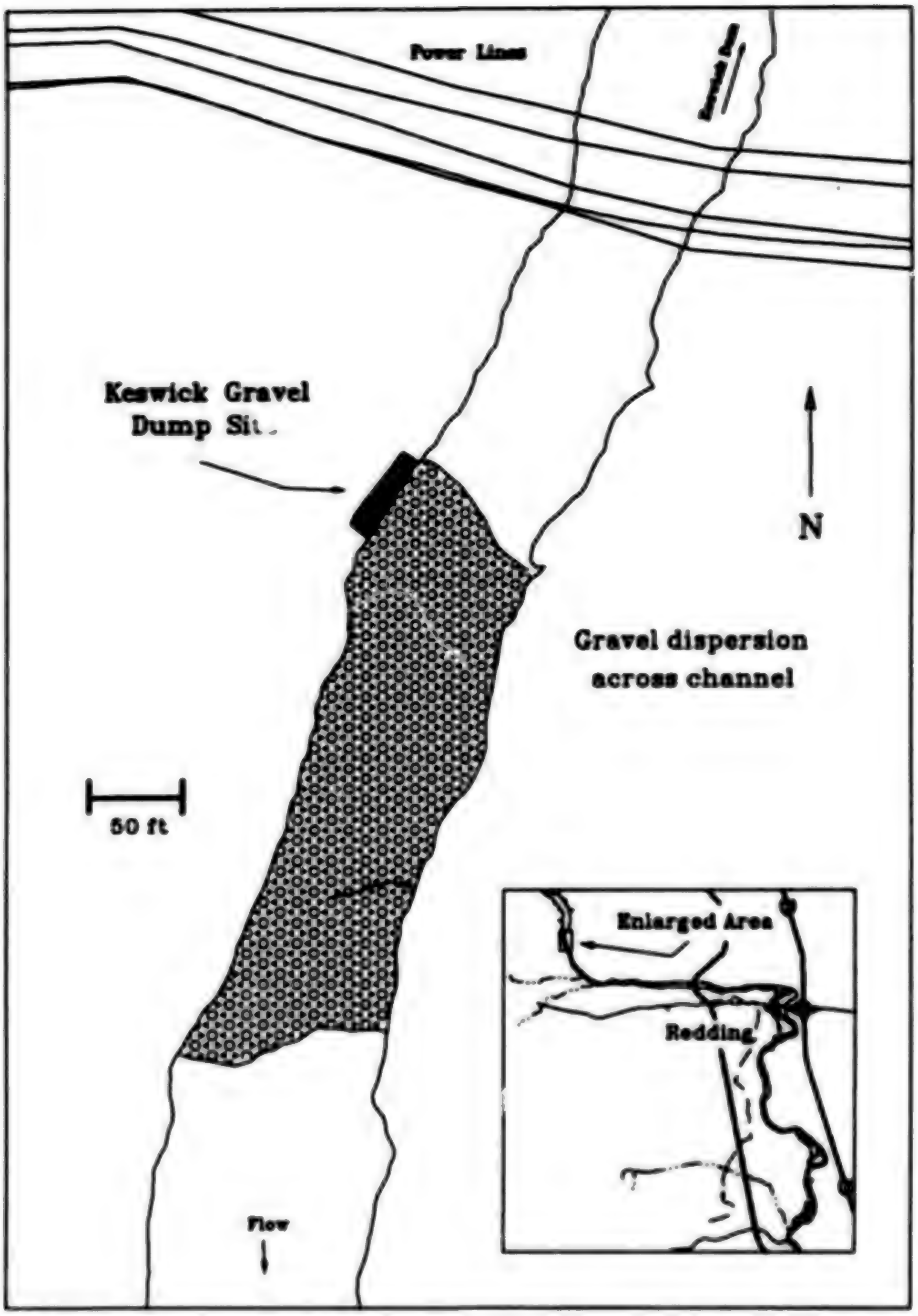
Appendix A

Keswick Site

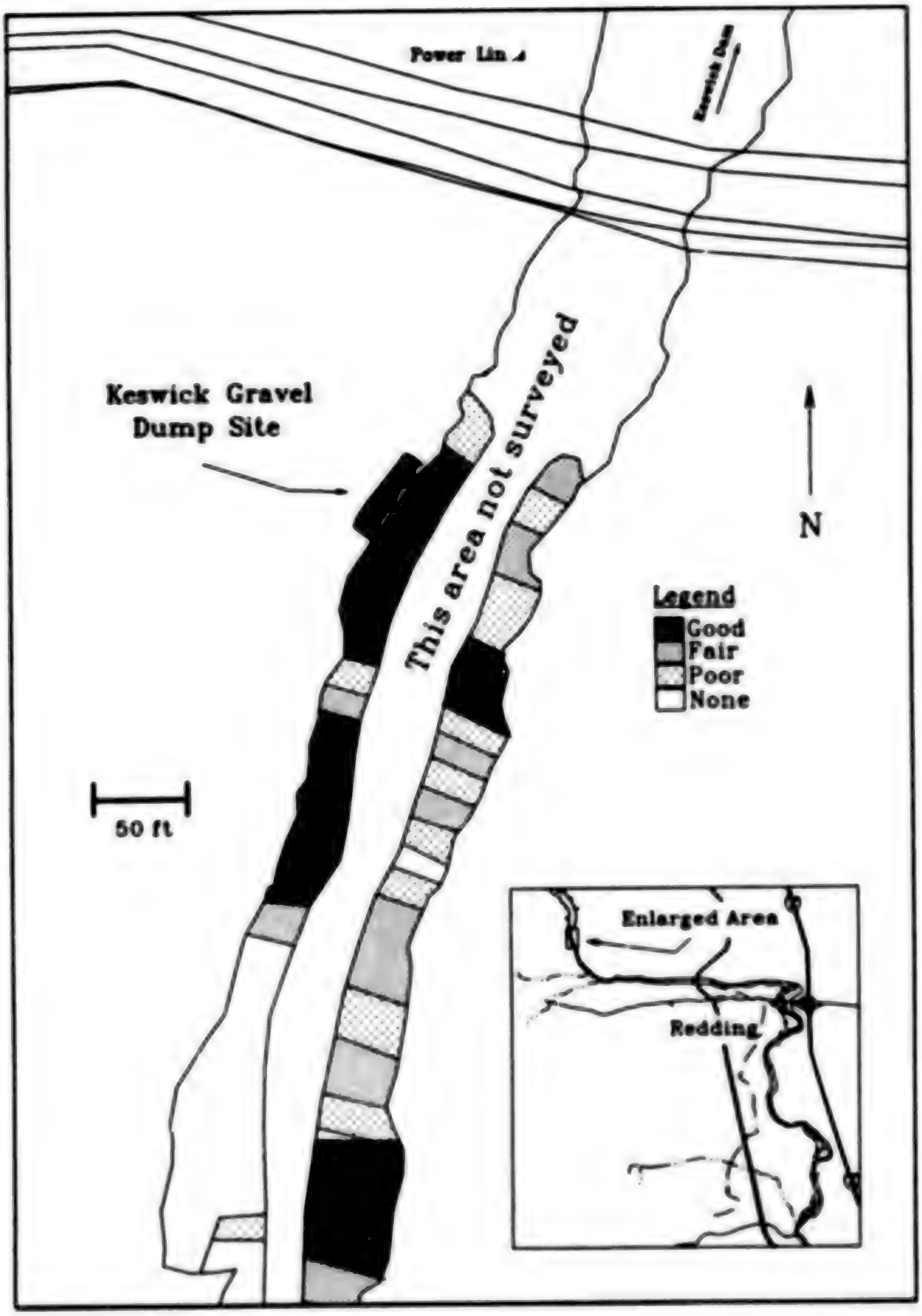
Appendix 1a.—Keswick Dam gravel site (RM 302.0) in the Sacramento River, March 1992.



Appendix 1b.—Keswick Dam gravel site in the Sacramento River, May 1992. Some gravel sloughing is apparent, but majority of gravel remains piled on the river bank.



Appendix 2.—Keswick gravel restoration site, 1992. Gravel has sloughed off the dump pile and moved across the channel and downstream creating good spawning substrate for over 500 ft.

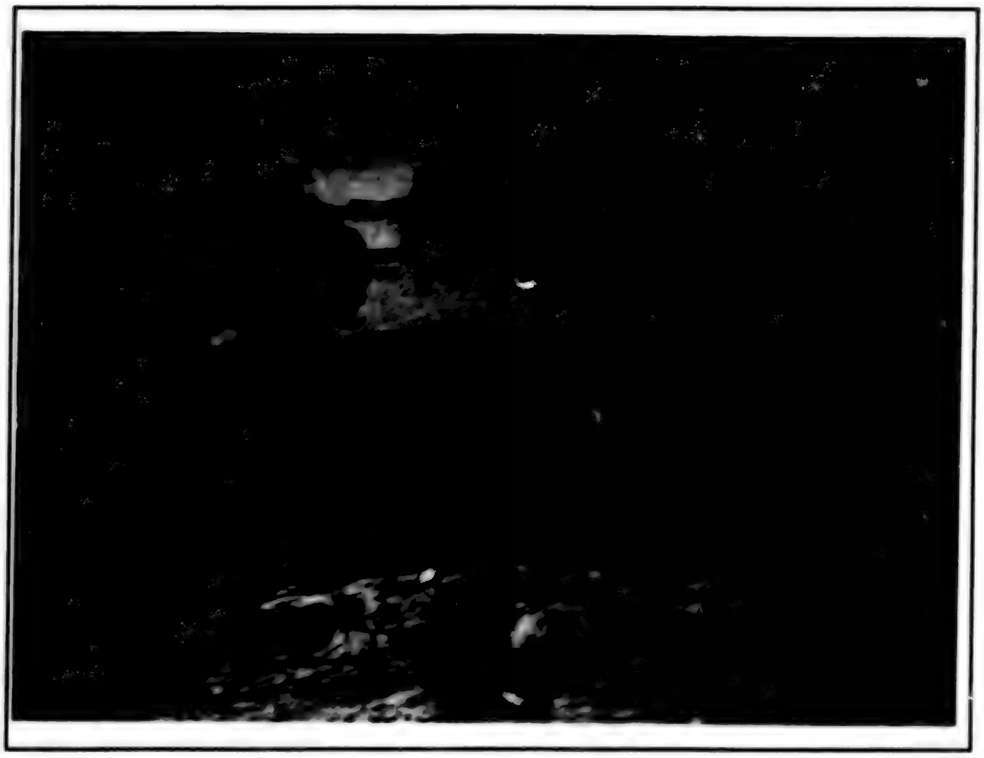


Appendix 3.—Spawning suitability substrate map for the Sacramento River below the Keswick gravel restoration site, 1993.

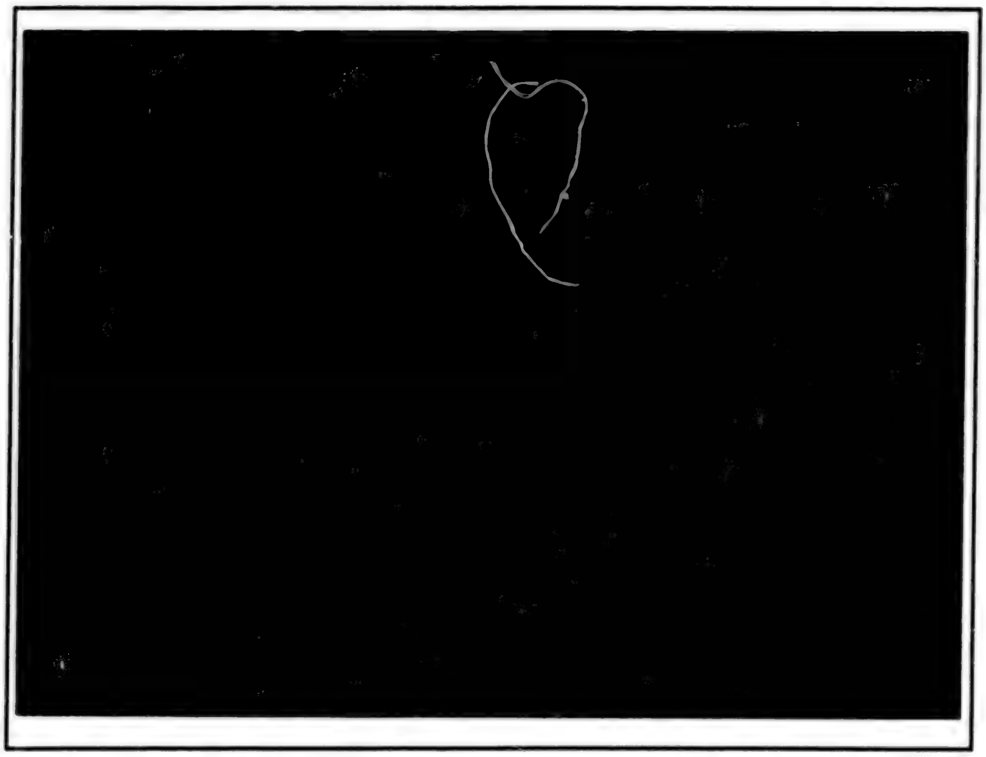
Appendix B

Salt Creek Site

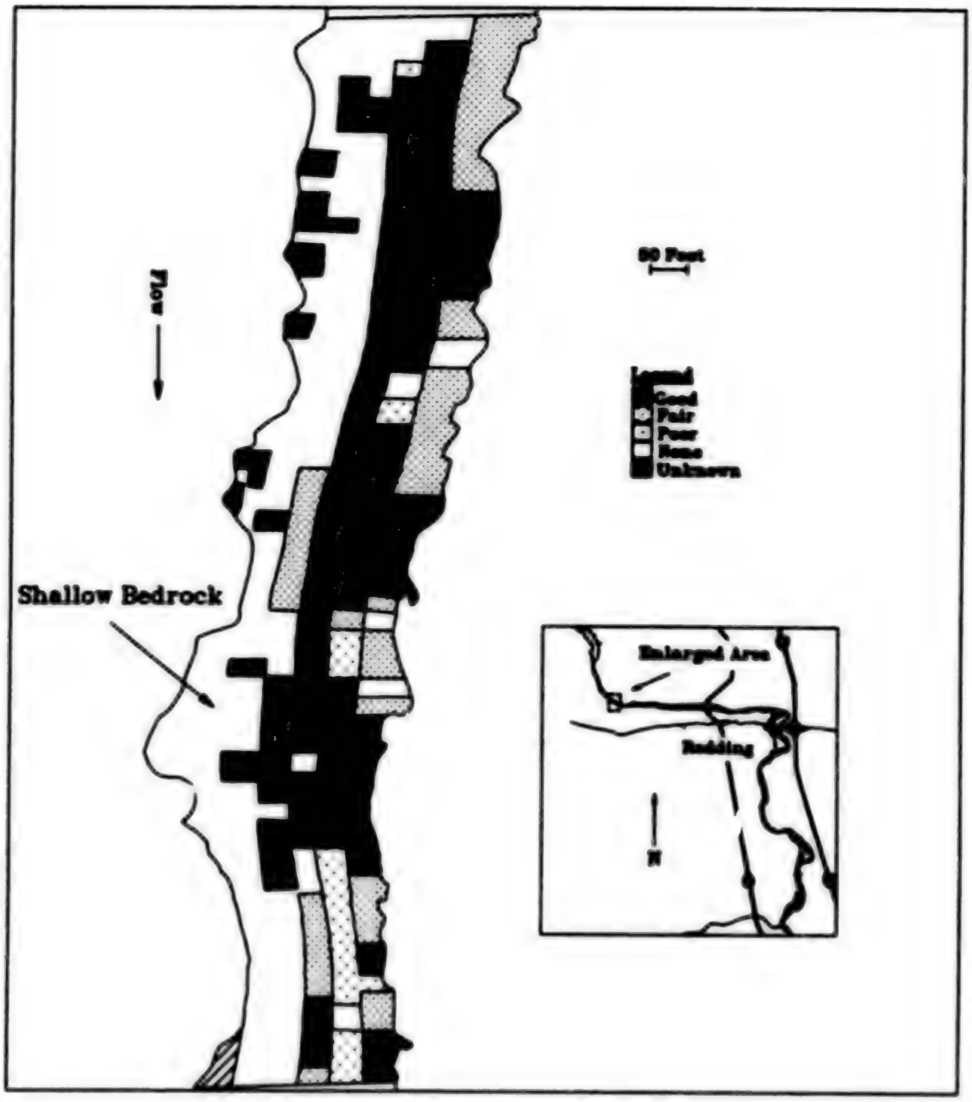
Appendix 4a.—Salt Creek gravel site (RM 301.0) in the Sacramento River, October, 1991. Majority of new gravel remained piled on the north bank of the river. Flow release from Keswick Dam was approximately 4,400 ft^3/s.



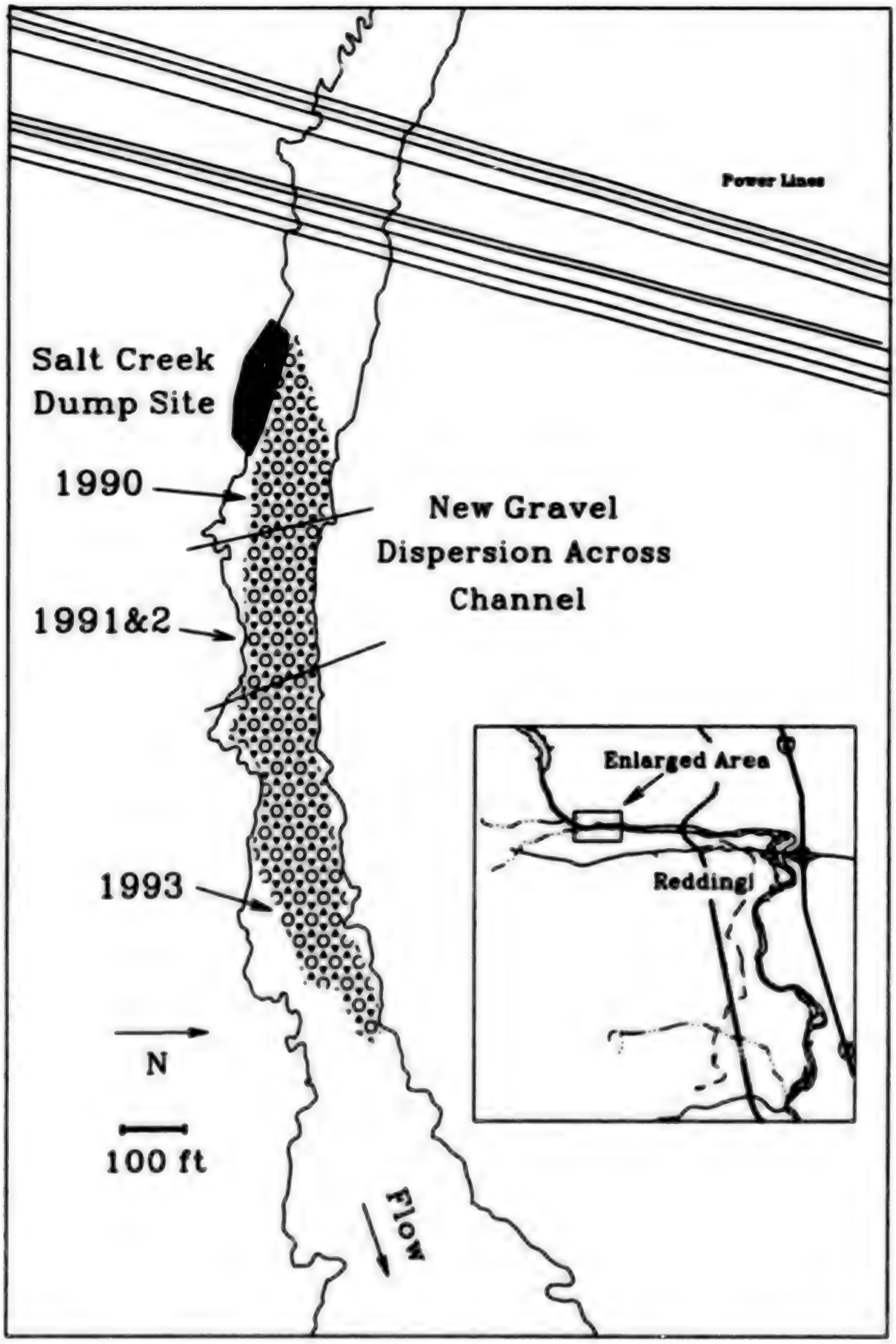
Appendix 4b.—Salt Creek gravel site in the Sacramento River, November 1992. New gravel had moved across the channel and downstream 0.25 mi. Flow release from Keswick Dam was approximately 3,100 ft^3/s.



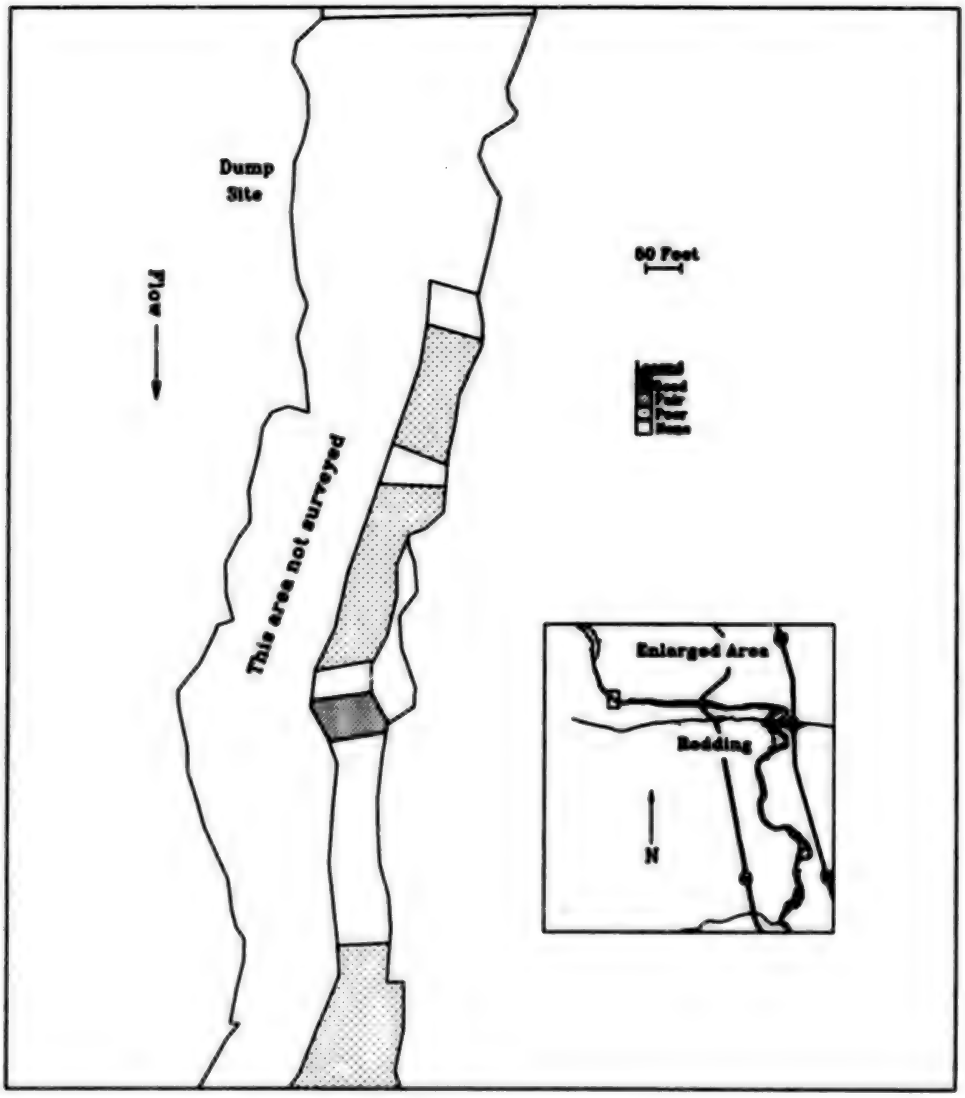
Appendix 4c.—Salt Creek gravel site in the Sacramento River, April 1993. High flows in 1993 moved almost all the gravel here downstream. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



Appendix 5.—Spawning suitability substrate map for Sacramento River just below the Salt Creek gravel site, 1990. Most of the right bank, where the gravel was placed, is shallow and dominated by bedrock and higher water velocities, which explains why no gravel deposition occurred in this area.



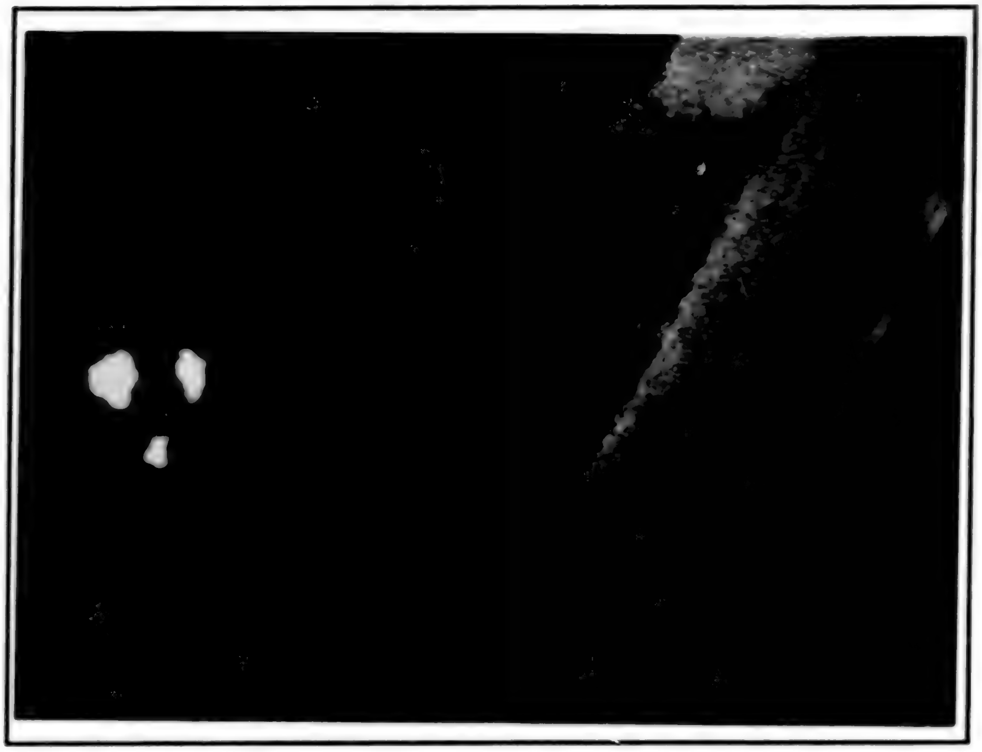
Appendix 6.—Extent of spawning gravel movement at the Salt Creek site. The lateral lines depict the extent of gravel movement from the placement site found in 1990, 1991, 1992 and 1993.



Appendix 7.—Spawning suitability substrate map for Sacramento River just below the Salt Creek gravel site, 1993.

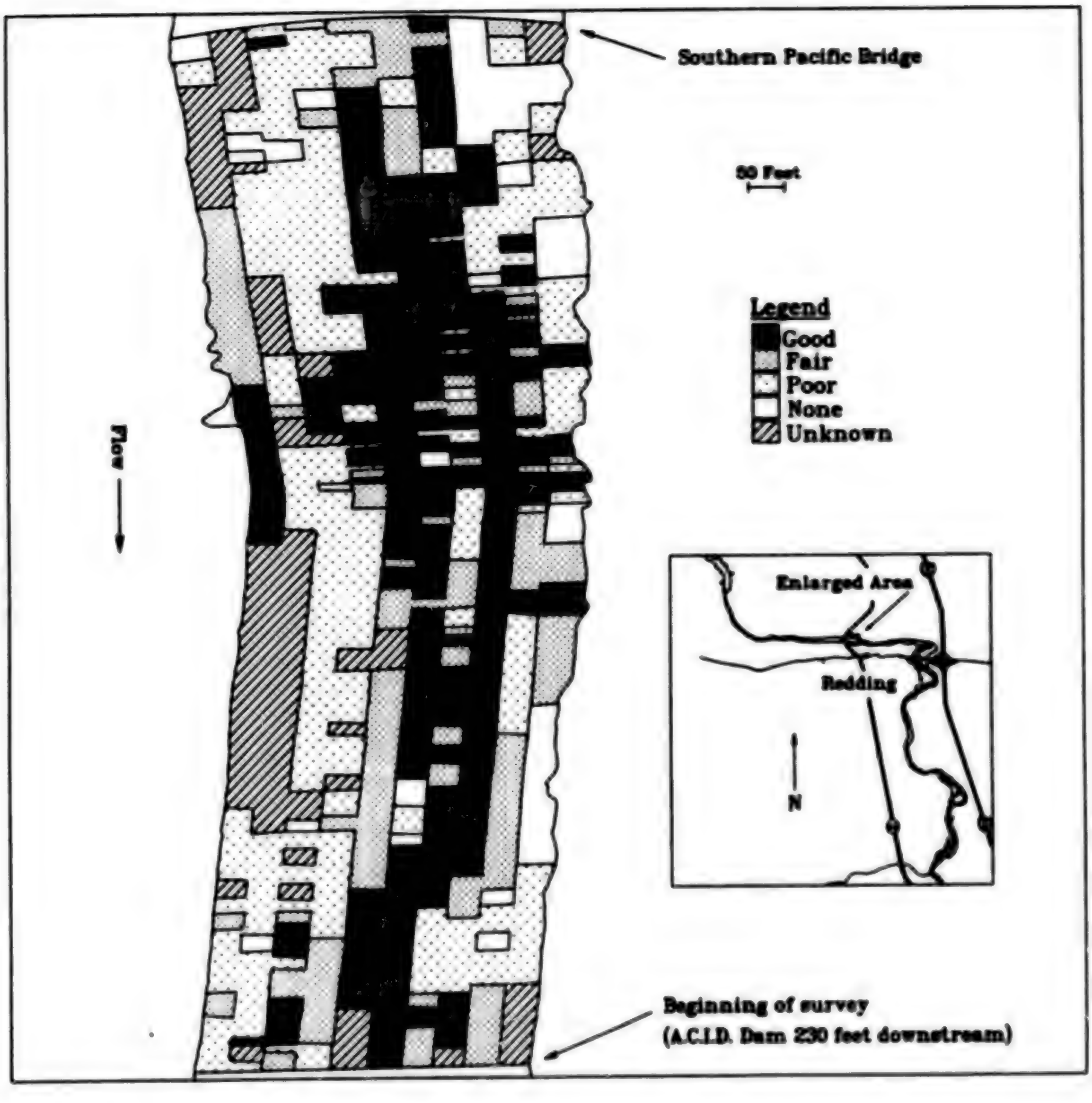
Appendix C

Diestelhorst Site

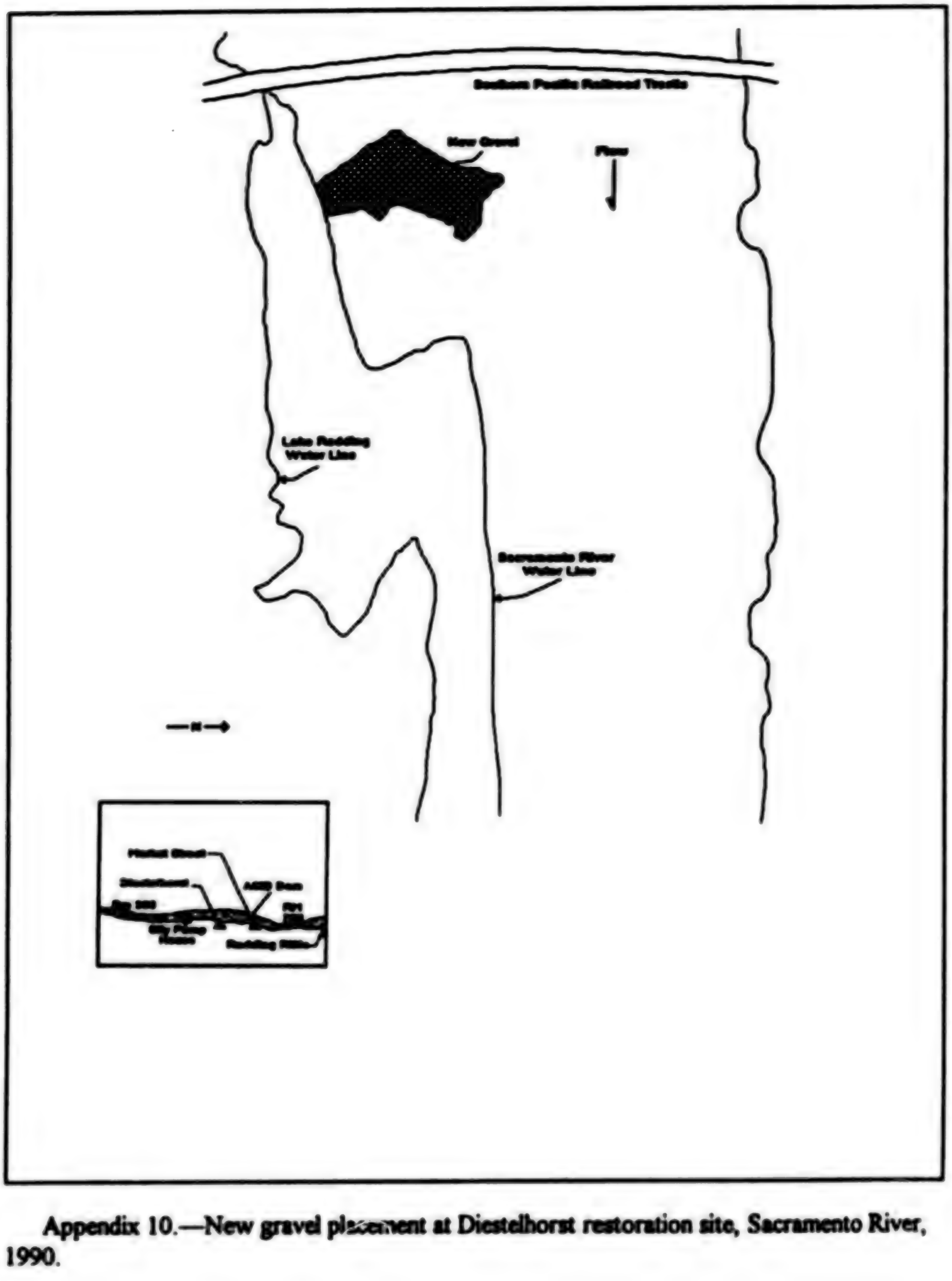


Appendix 8a.—Diestelhorst gravel restoration site (RM 298.8), Sacramento River, November, 1991. New gravel is easily discerned by its darker color.

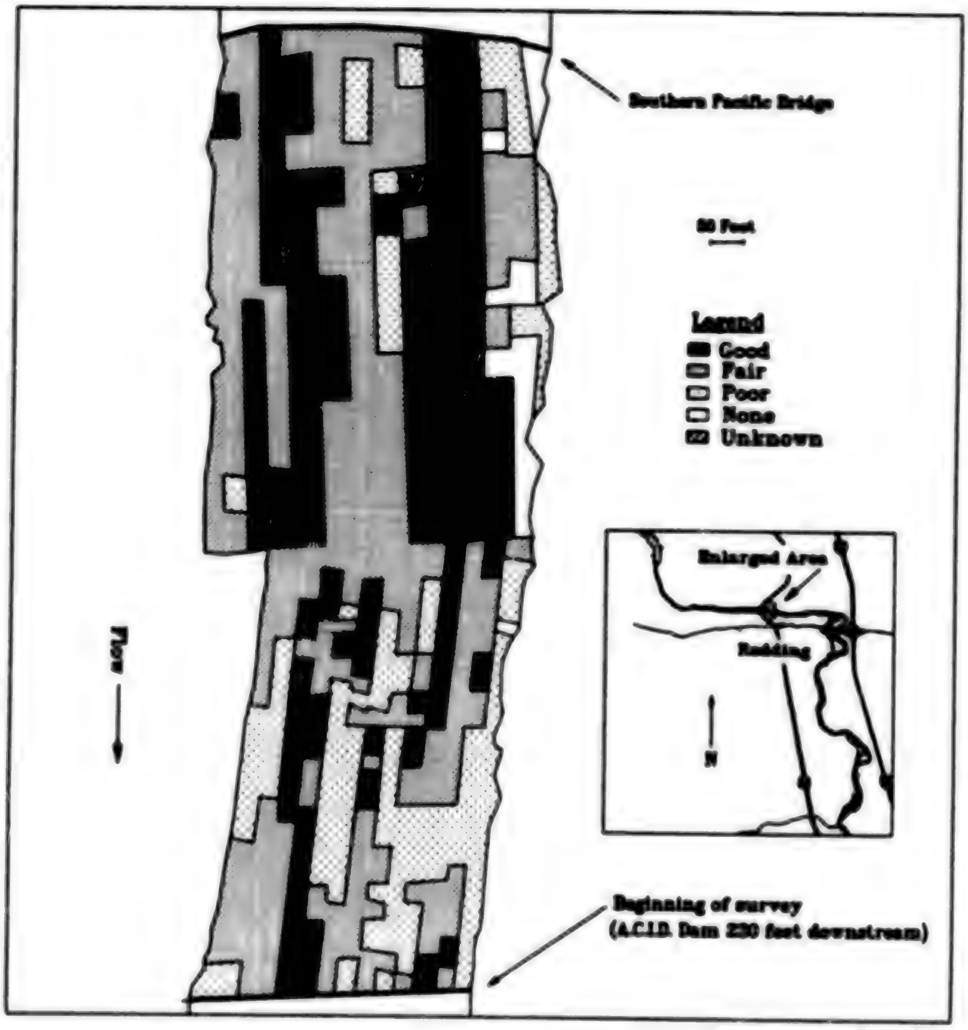
Appendix 8b.—Diestelhorst gravel restoration site, Sacramento River, April 1993. New gravel has been displaced downstream by high river flows. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



Appendix 9.—Spawning suitability substrate map for Sacramento River just below Diestelhorst restoration site, 1990. Substrate determinations were made before the addition of spawning gravel.



Appendix 10.—New gravel placement at Diestelhorst restoration site, Sacramento River, 1990.

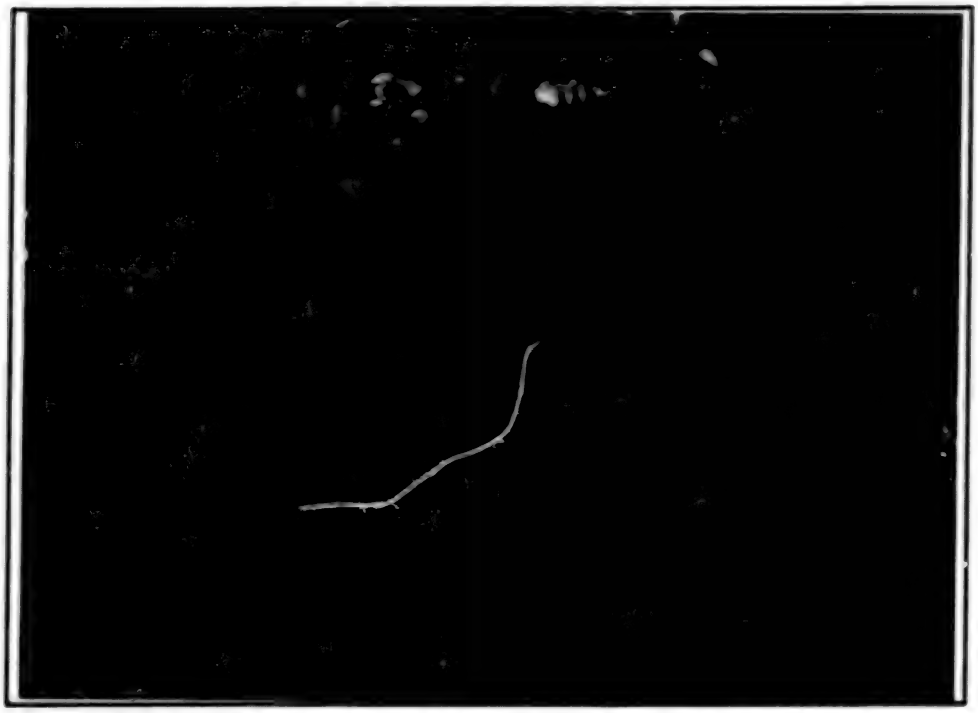


Appendix 11.—Spawning suitability substrate map for the Sacramento River at the Diestelhorst site, 1993.

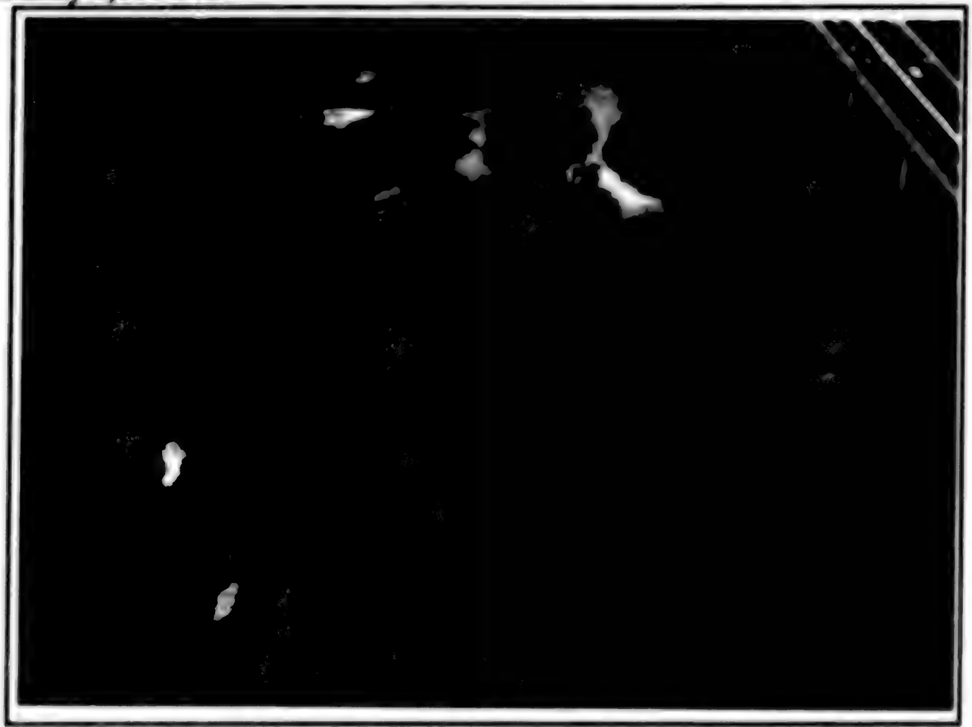
Appendix D

Market Street Bridge Site

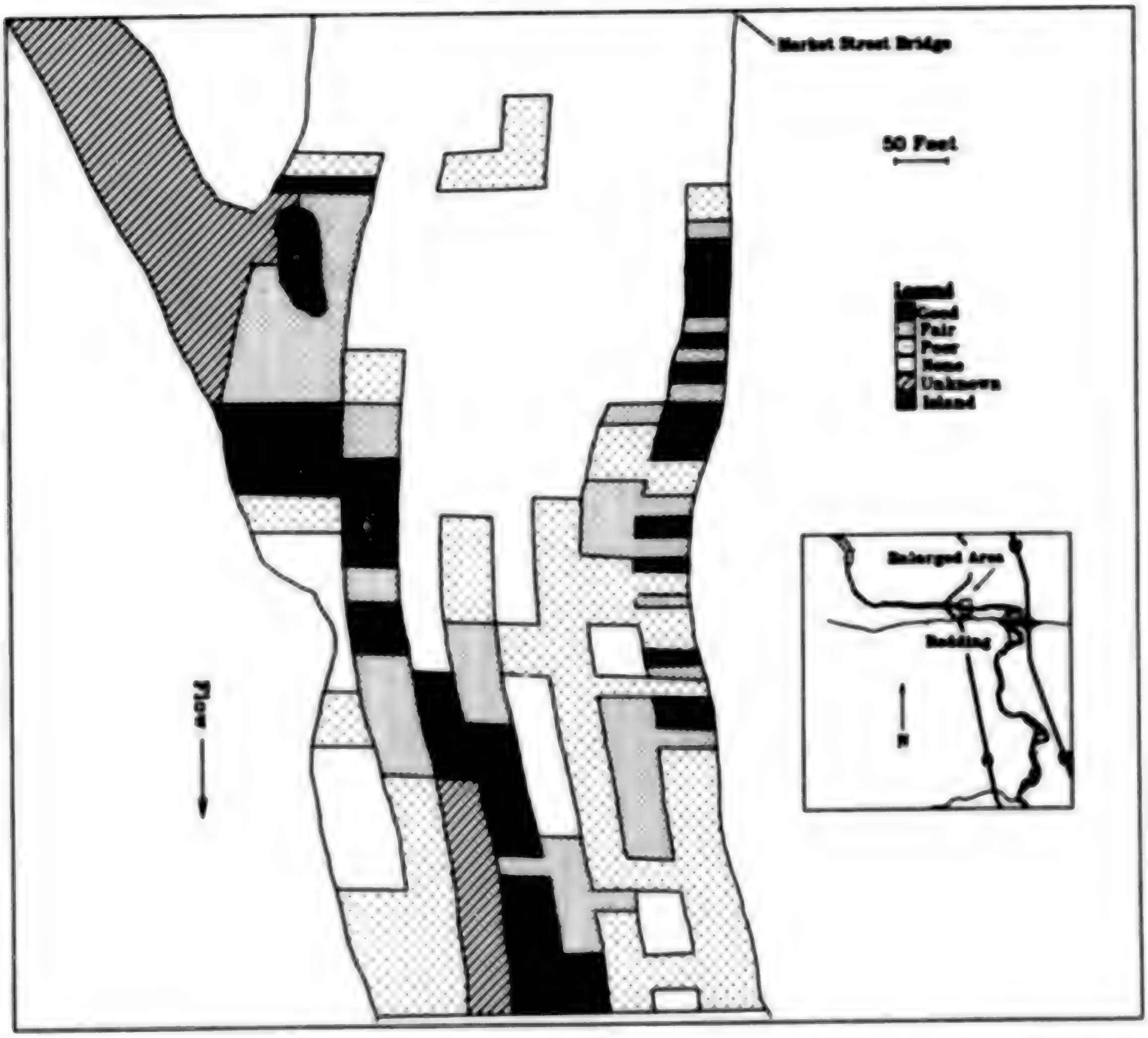
Appendix 12a.—Market Street Bridge gravel restoration site (RM 298.4), Sacramento River, May 1991. Gravel was smoothed to an elevation below the low-flow water surface level, immediately providing spawning substrate for adult salmon.



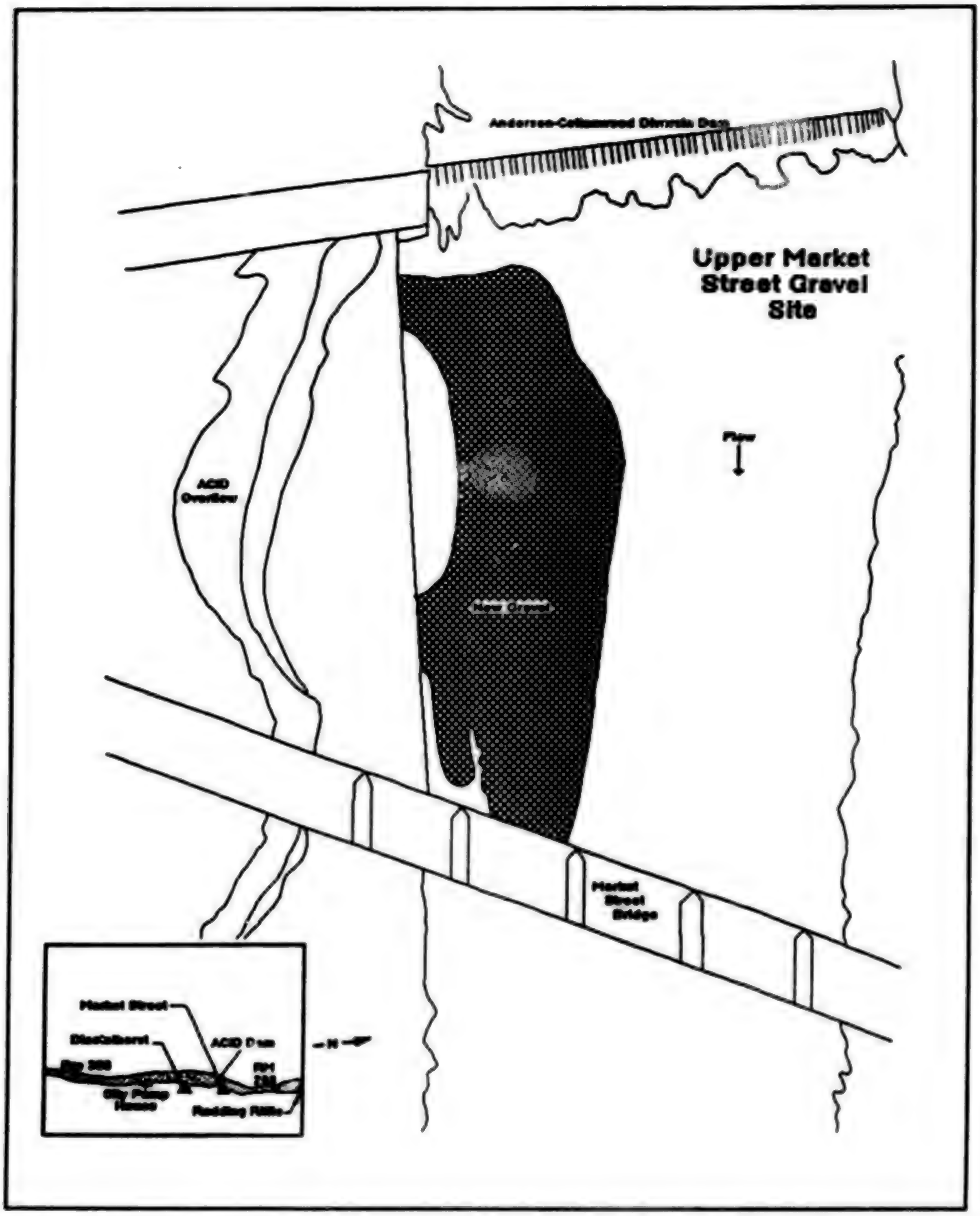
Appendix 12b.—Lower Market Street Bridge gravel restoration site, June 1992. The majority of new gravel remains where initially placed, however, some gravel has moved downstream, extending the length of the gravel patch. Flow release from Keswick Dam was approximately 6,800 ft^3/s.



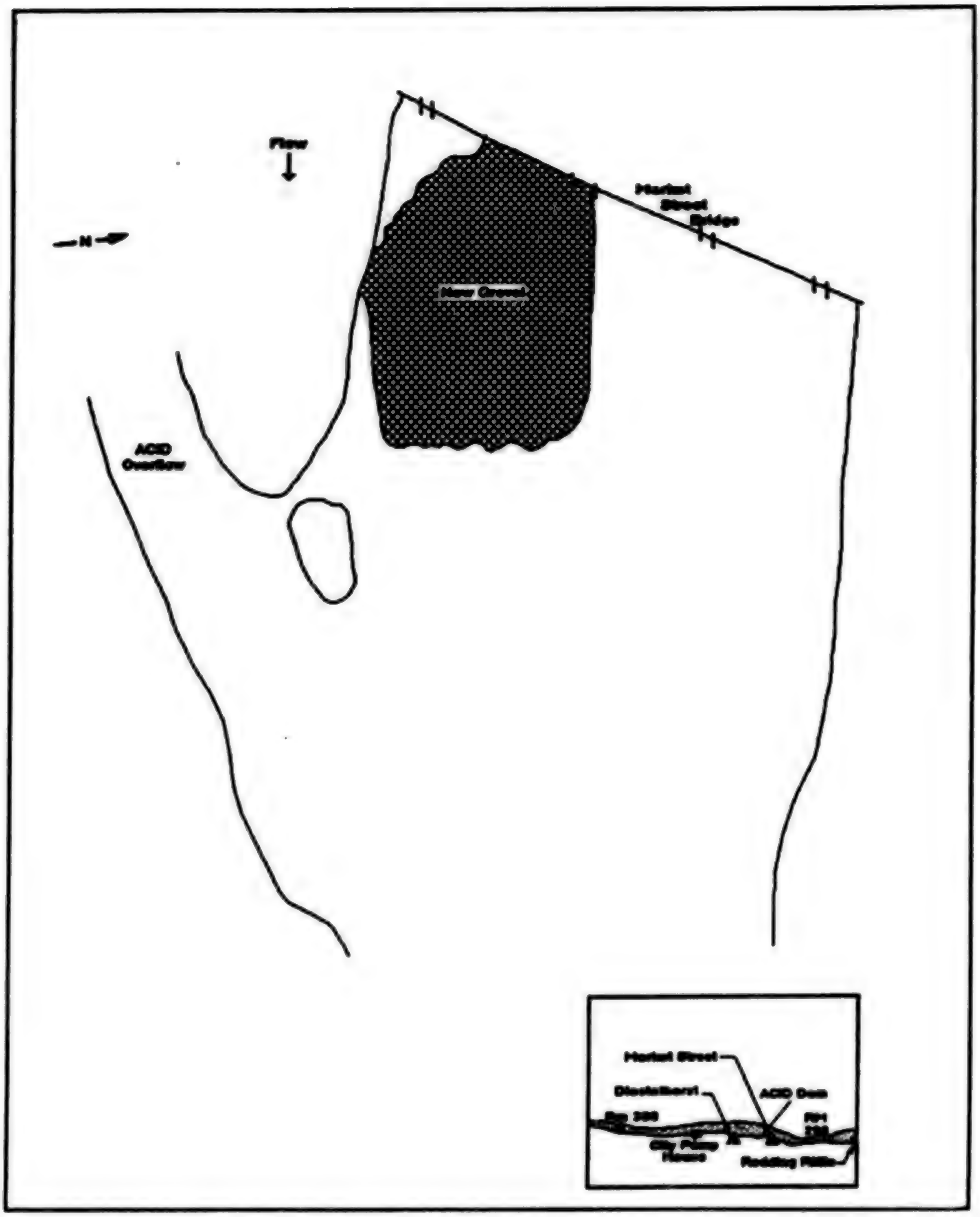
Appendix 12c.—Lower Market Street Bridge gravel restoration site, April 1993. Very little of the new gravel remains where originally placed. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



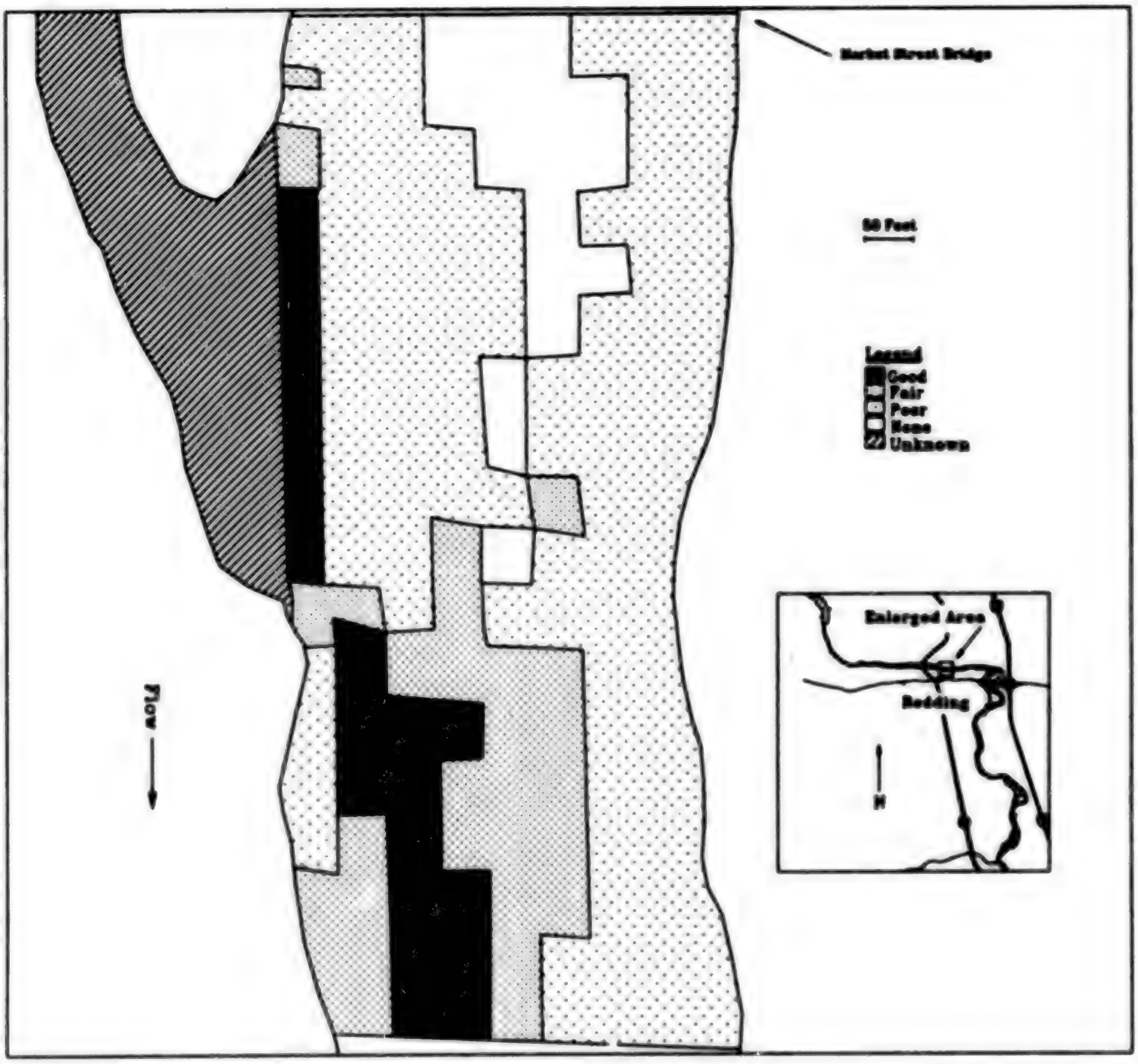
Appendix 13.—Spawning suitability substrate map for Sacramento River at the Market Street Bridge site, 1990. Substrate determinations were made before the addition of spawning gravel. The area above the bridge was not mapped.



Appendix 14a.—New gravel placement upstream of the bridge at Market Street Bridge restoration site, Sacramento River (RM 298).



Appendix 14b.—New gravel placement downstream of the bridge at Market Street Bridge restoration site, Sacramento River (RM 298).

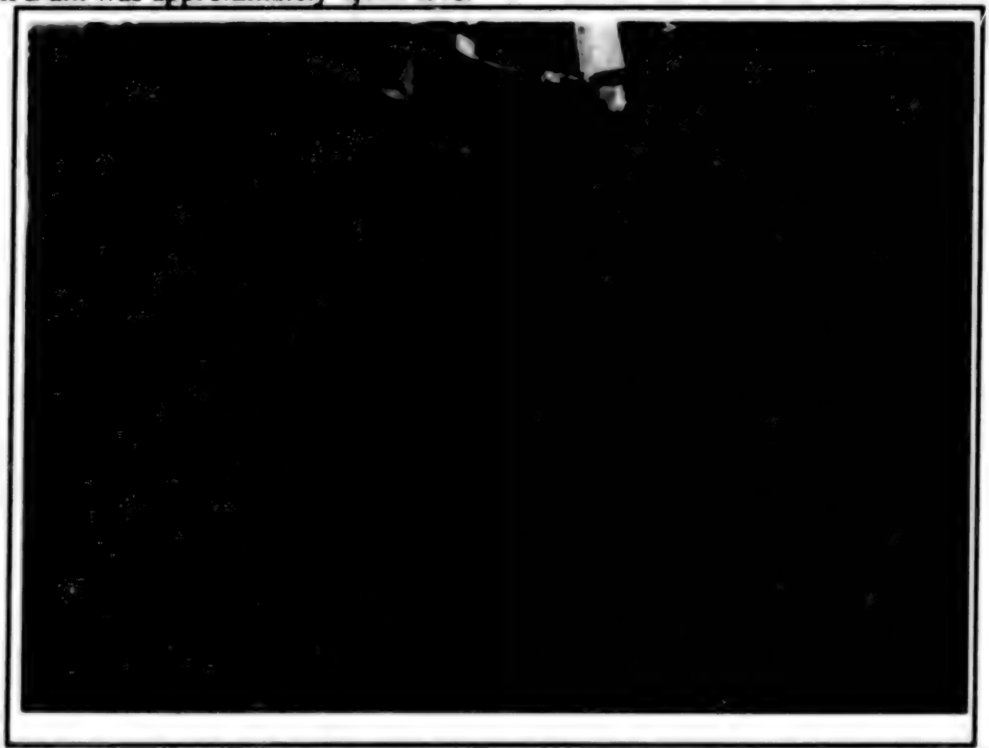


Appendix 15.—Spawning suitability substrate map for the Sacramento River at the Market Street Bridge site, 1993.

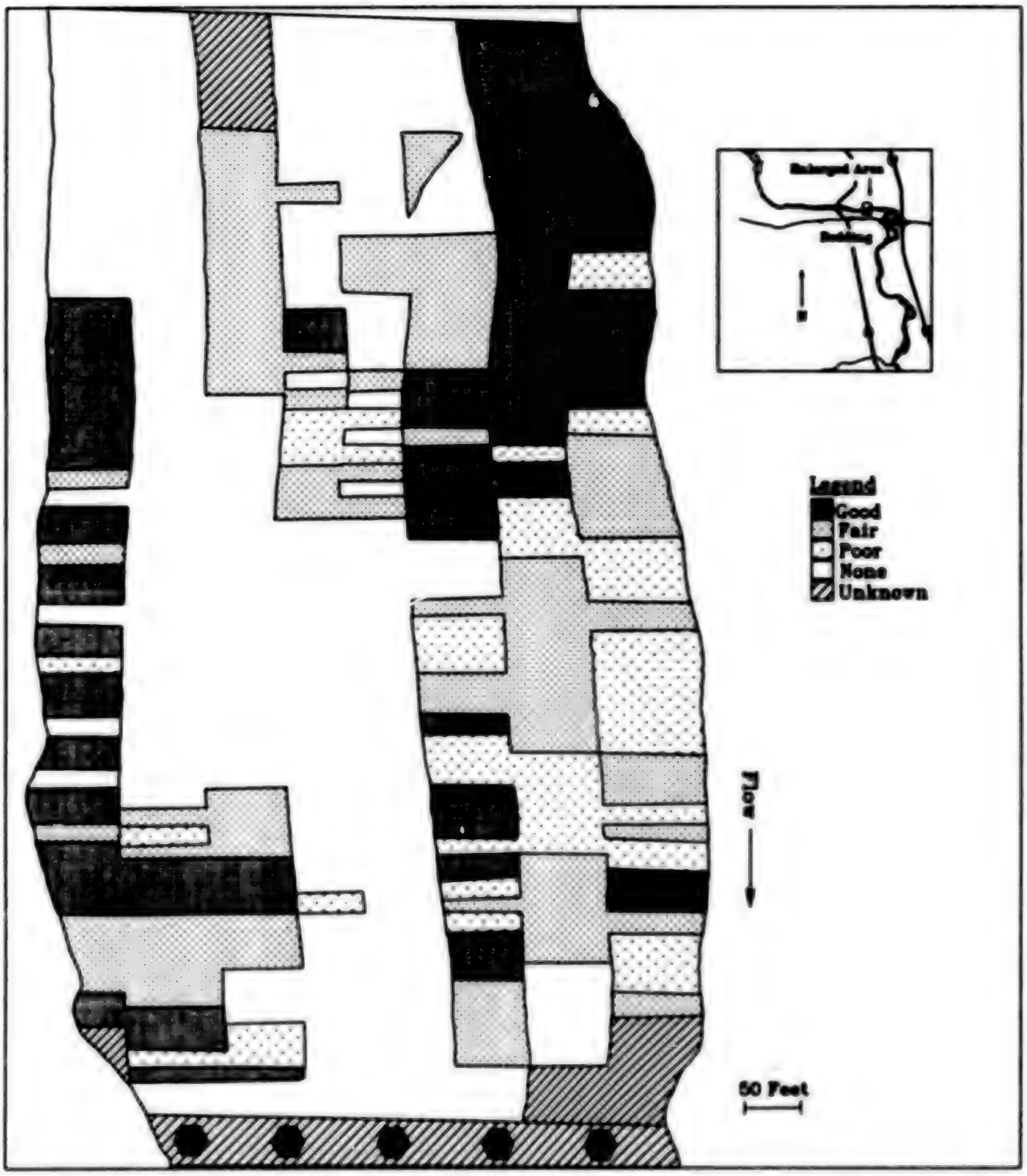
Appendix E

Redding Riffle Site

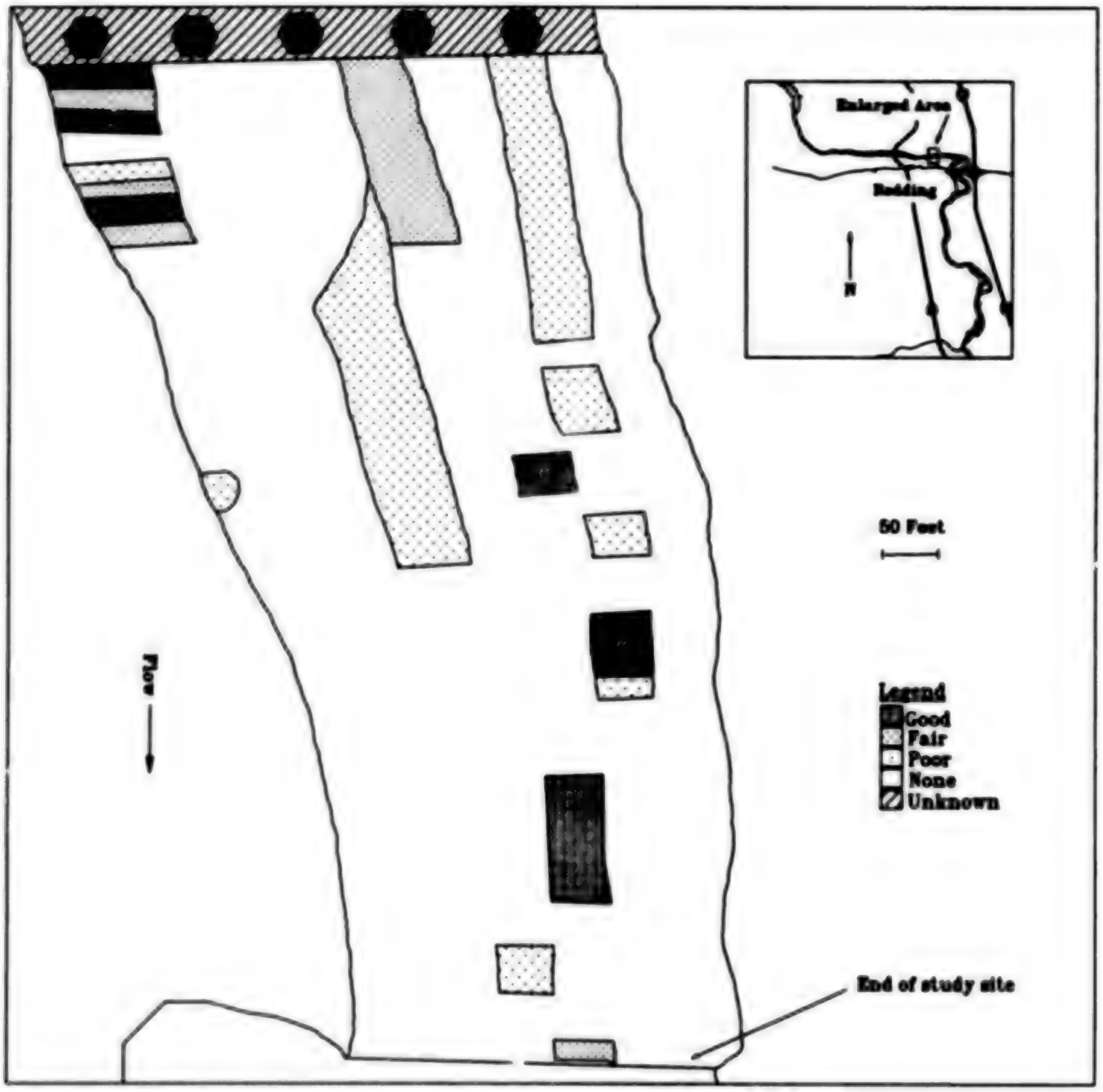
Appendix 16a.—Redding Riffle gravel restoration site (RM 298.3), Sacramento River, October, 1991. A significant percentage of fall-run chinook redds counted during 1991 were constructed in Market Street Bridge and Redding Riffle gravel areas. Flow release from Keswick Dam was approximately 4,800 ft^3/s.



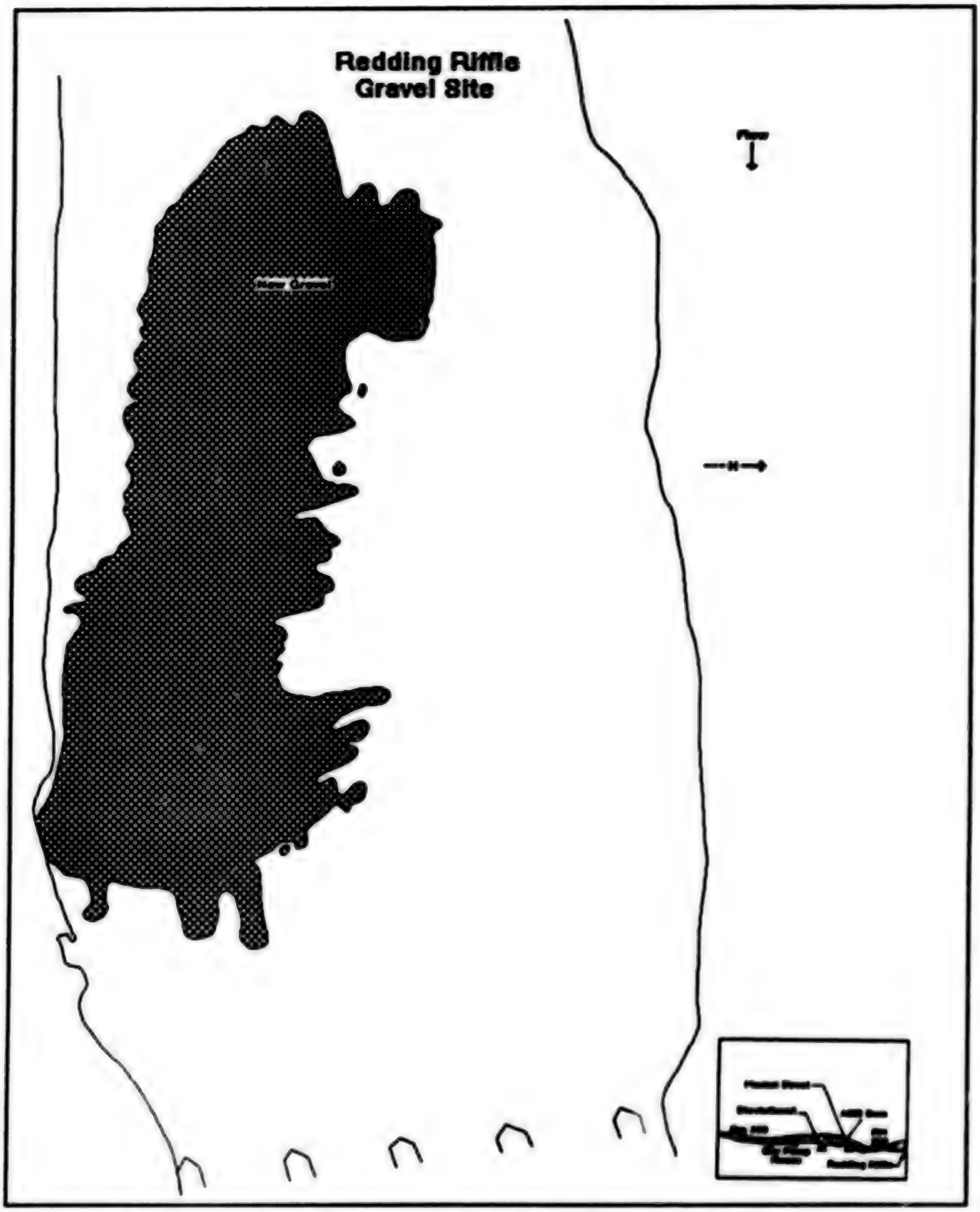
Appendix 16b.—Redding Riffle gravel restoration site, Sacramento River, April 1993. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



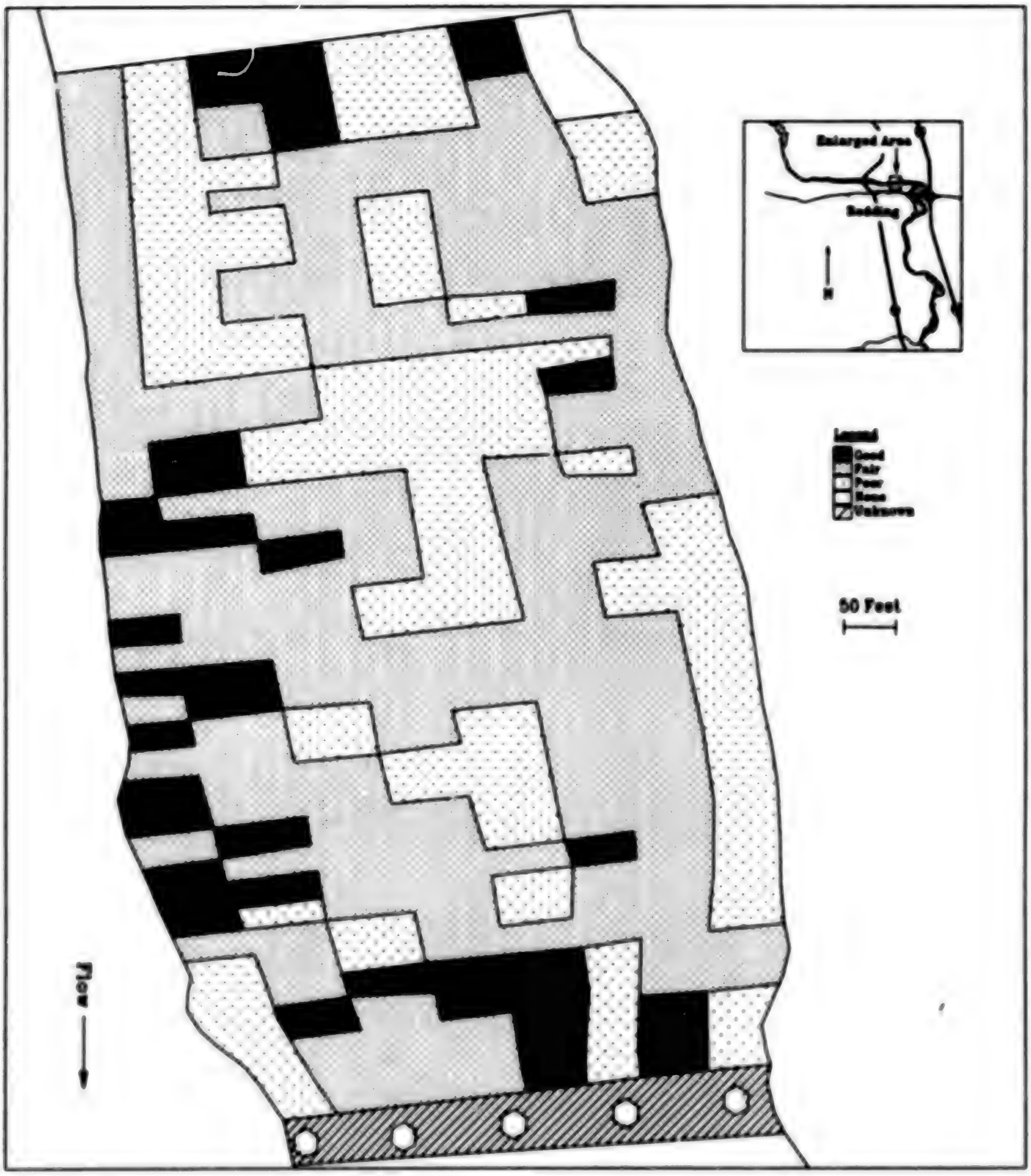
Appendix 17a.—Spawning suitability substrate map for Sacramento River at the Redding Riffle site (upper section), 1990. Substrate determinations were made prior to the addition of spawning gravel.



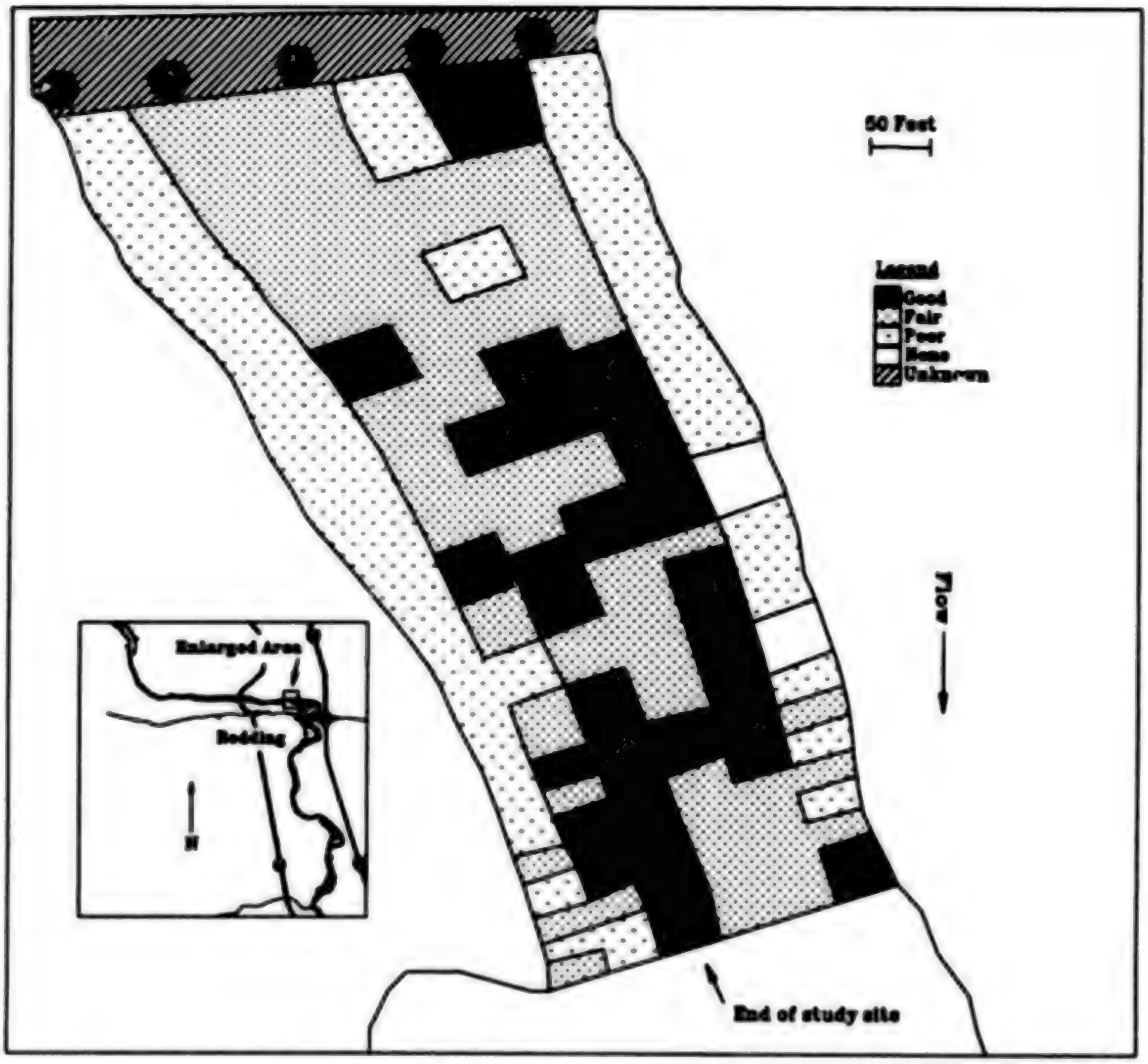
Appendix 17b.—Spawning suitability substrate map for Sacramento River at the Redding Riffle site (lower section), 1990. Substrate determinations were made prior to the addition of spawning gravel.



Appendix 18.—New gravel placement at Redding Riffle restoration site, Sacramento River (RM 298).



Appendix 19a.—Spawning suitability substrate map for Sacramento River at the Redding Riffle site (upper section), 1993.



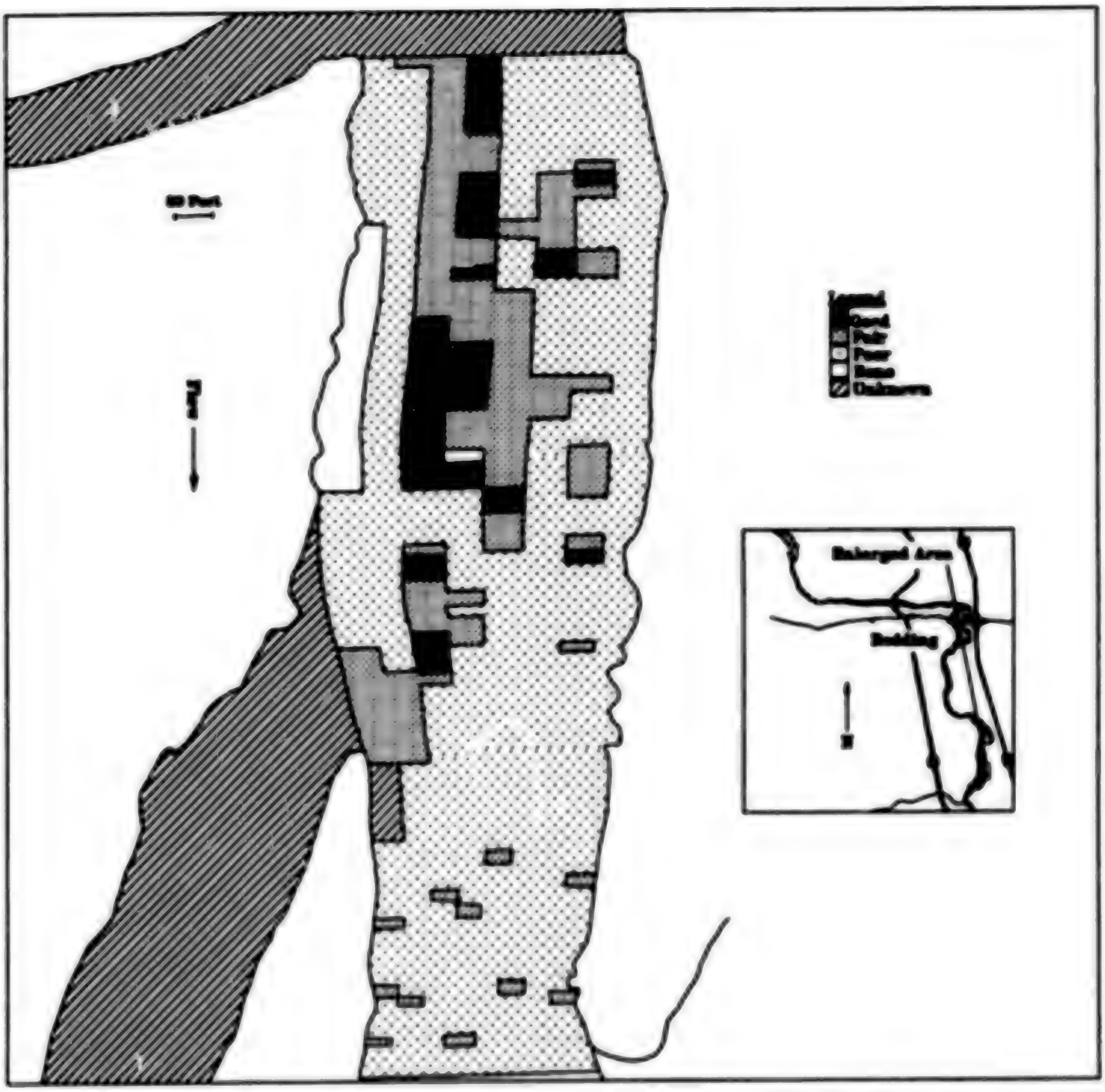
Appendix 19b.—Spawning suitability substrate map for Sacramento River at the Redding Riffle site (lower section), 1993.

Appendix F

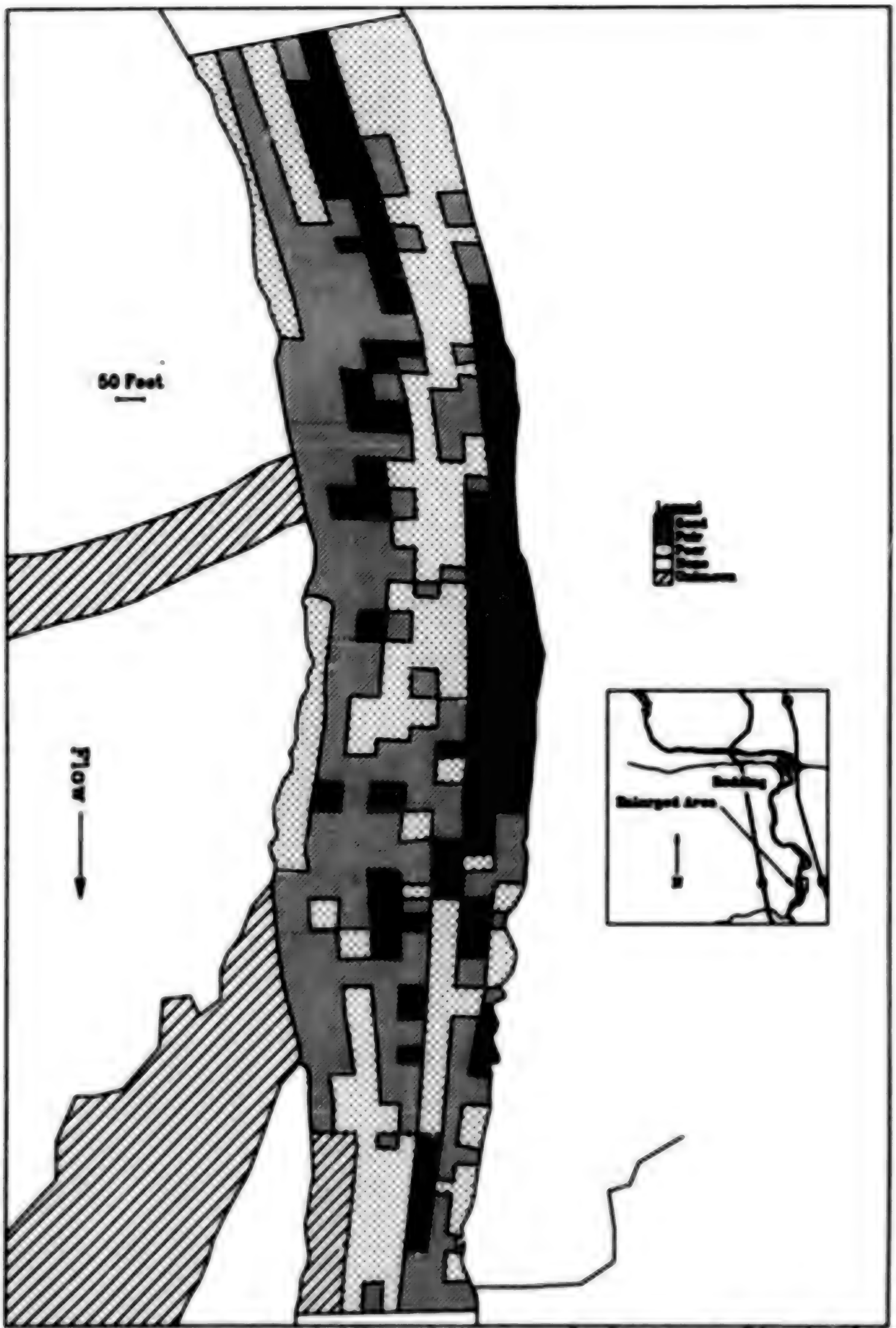
Shea Levee Site

Appendix 20a.—Shea Levee gravel restoration gravel site (RM 290.0), Sacramento River, November 1992. The majority of new gravel remained piled on the bank. Flow release from Keswick Dam was approximately 3,100 ft^3/s.

Appendix 20b.—Shea Levee gravel restoration gravel site Sacramento River, April 1993. Note the sloughing along the length of the gravel pile. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



Appendix 21.—Spawning suitability substrate map for Sacramento River just below Shea Levee site, 1990. Substrate determinations were made prior to addition of spawning gravel.



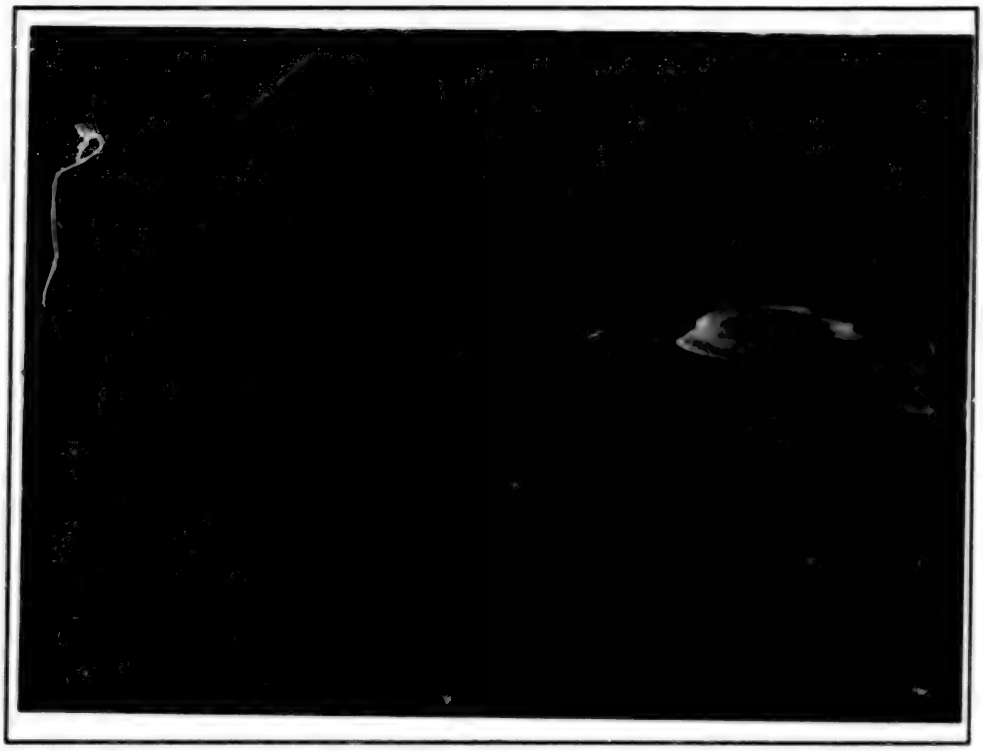
Appendix 22.—Spawning suitability substrate map for Sacramento River just below Shea Levre site, 1993.

Appendix G

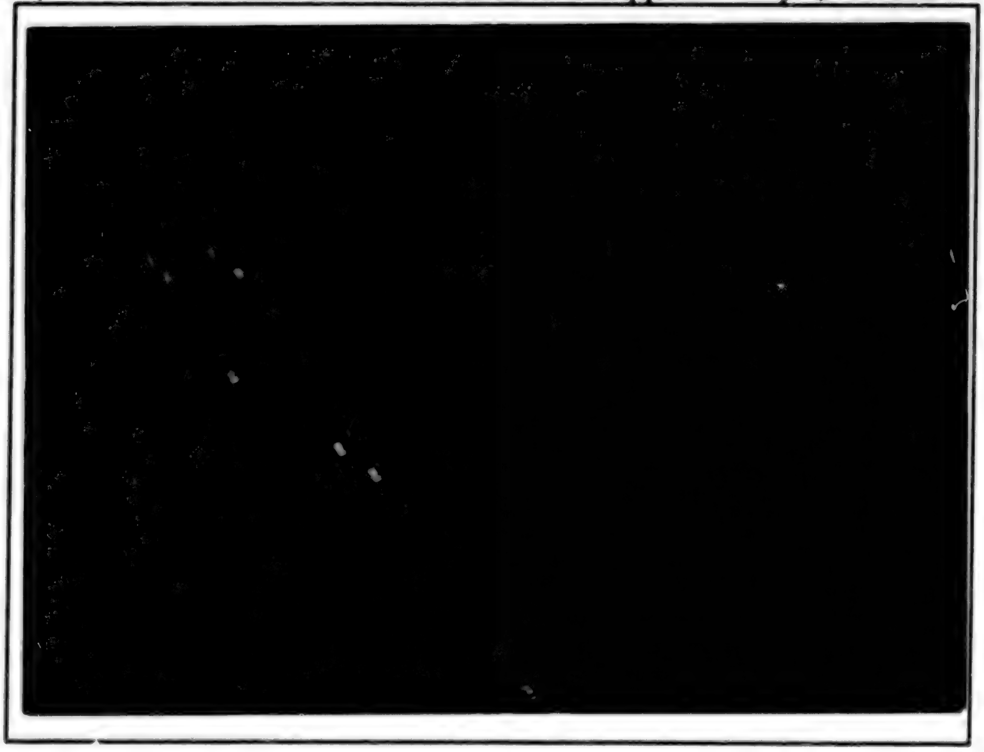
Remaining Restoration Sites

Appendix 23a.—Turtle Bay West gravel restoration site (RM 297.1), Sacramento River, October, 1991. Flow release from Keswick Dam was approximately 4,800 ft^3/s.

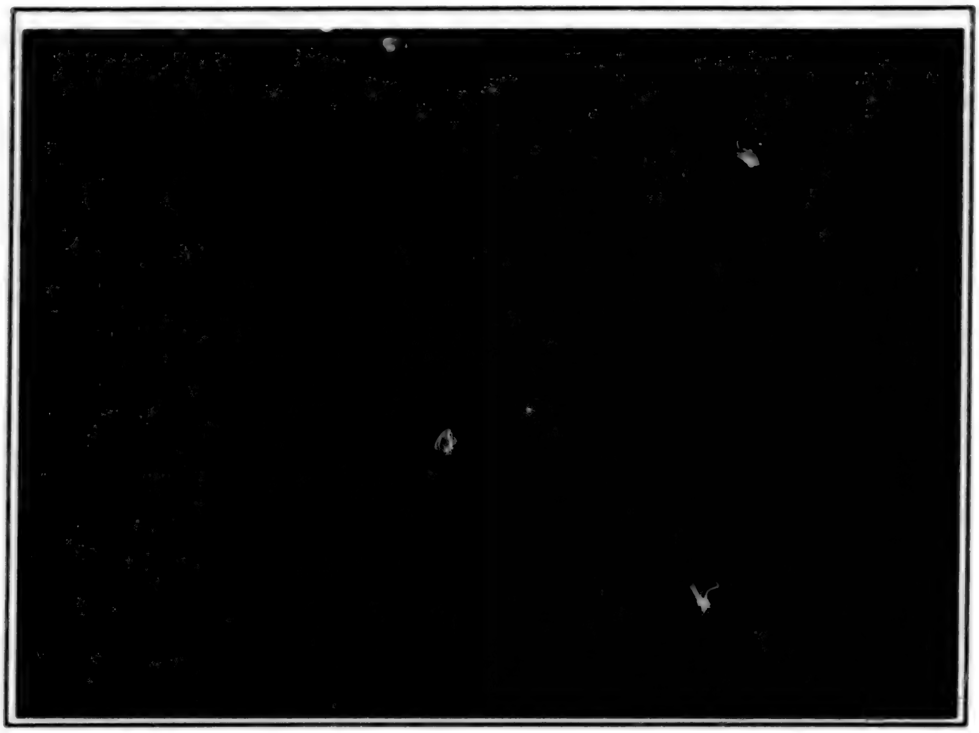
Appendix 23b.—Turtle Bay West gravel restoration site, Sacramento River, April 1993. No visible gravel remains at this site. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



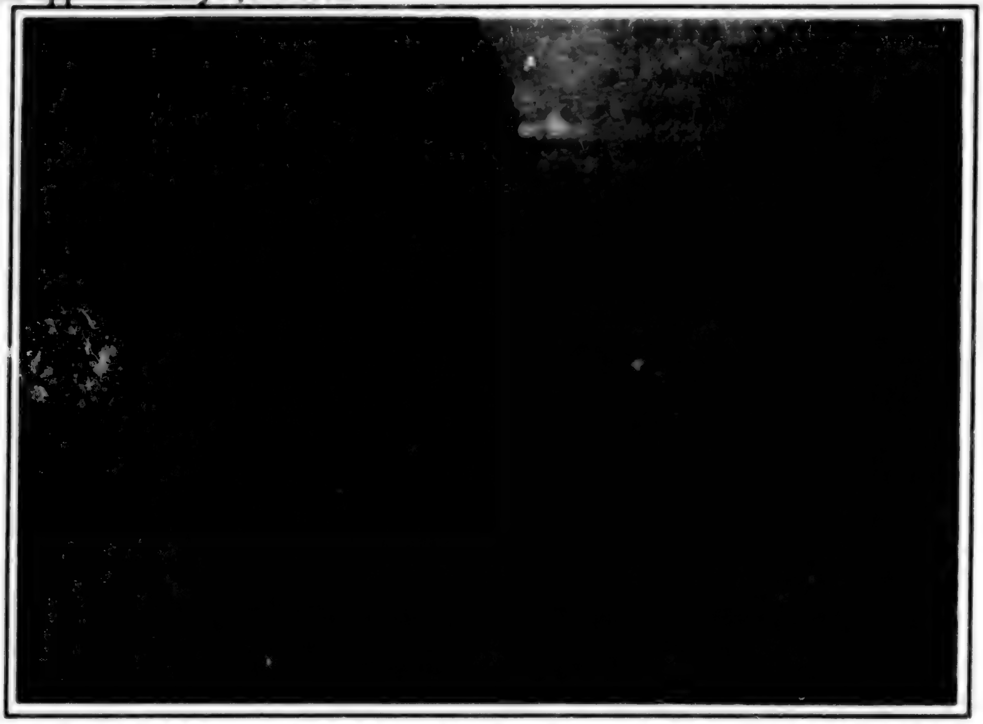
Appendix 24a.—Turtle Bay East gravel restoration site (RM 296.6), Sacramento River, November, 1991. Flow release from Keswick Dam was approximately 3,800 ft^3/s.



Appendix 24b.—Turtle Bay East gravel restoration site, Sacramento River, April 1993. The majority of new gravel has moved downstream of the highway 44 bridge. Flow release from Keswick Dam was approximately 4,500 ft^3/s.



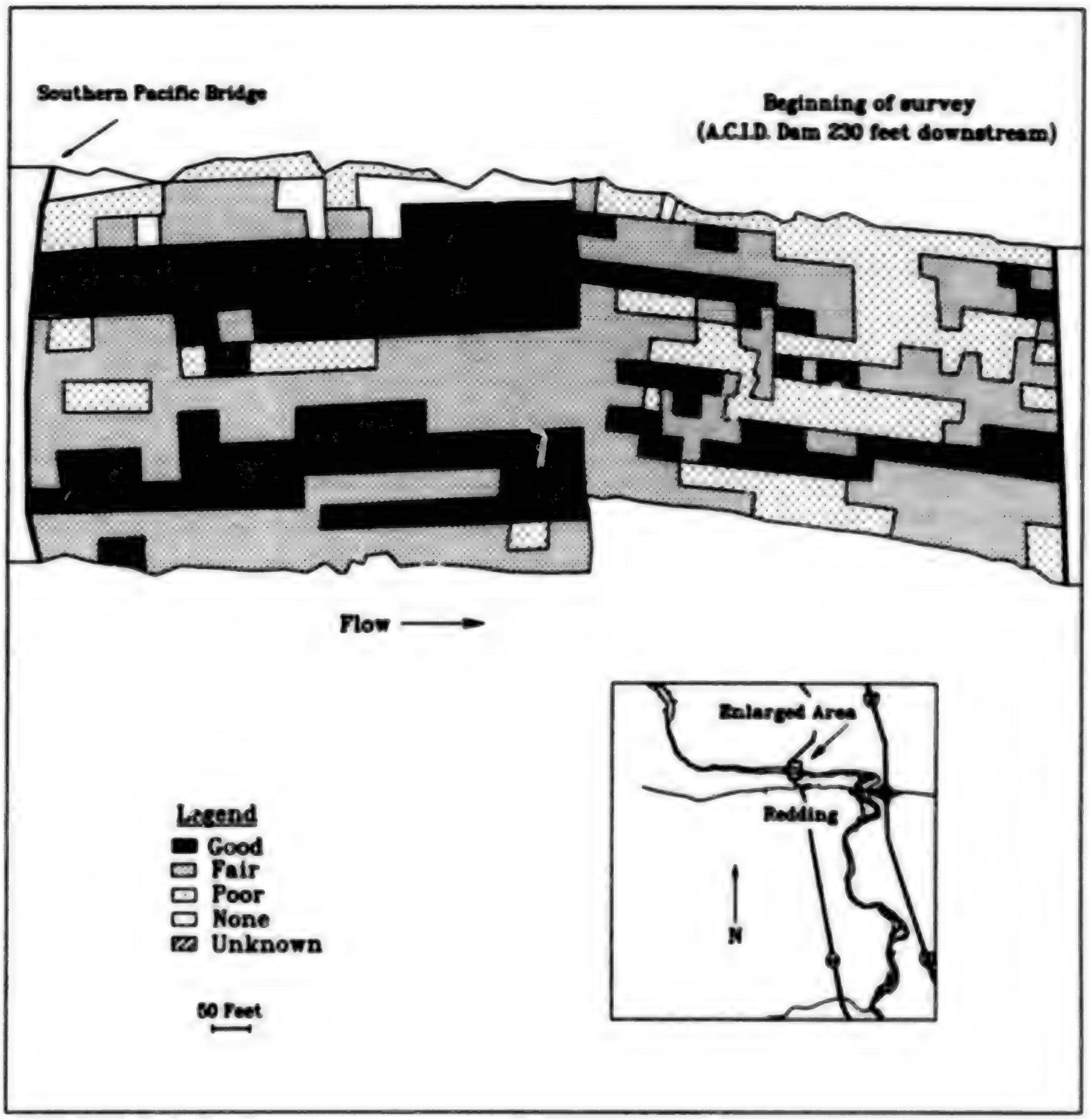
Appendix 25a.—Tobiasson Riffle gravel restoration site (RM 291.5), Sacramento River, November 1992. Majority of gravel remains piled on the bank. Flow release from Keswick Dam was approximately 3,100 ft^3/s.



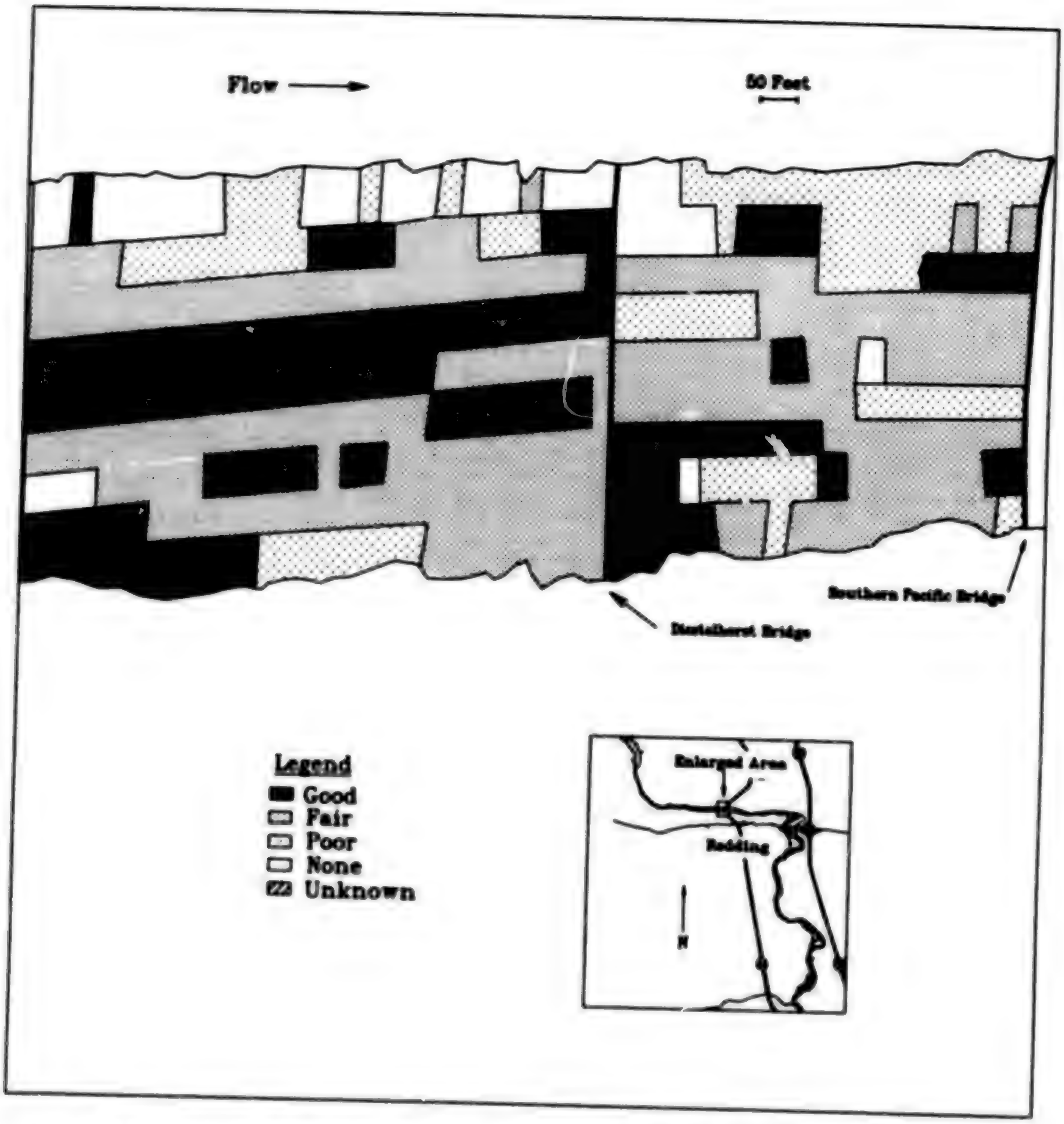
Appendix 25b.—Tobiasson Riffle gravel restoration site, Sacramento River, March 1993. Majority of gravel has sloughed off the bank and moved downstream. Flow release from Keswick Dam was approximately 48,200 ft^3/s.

Appendix H

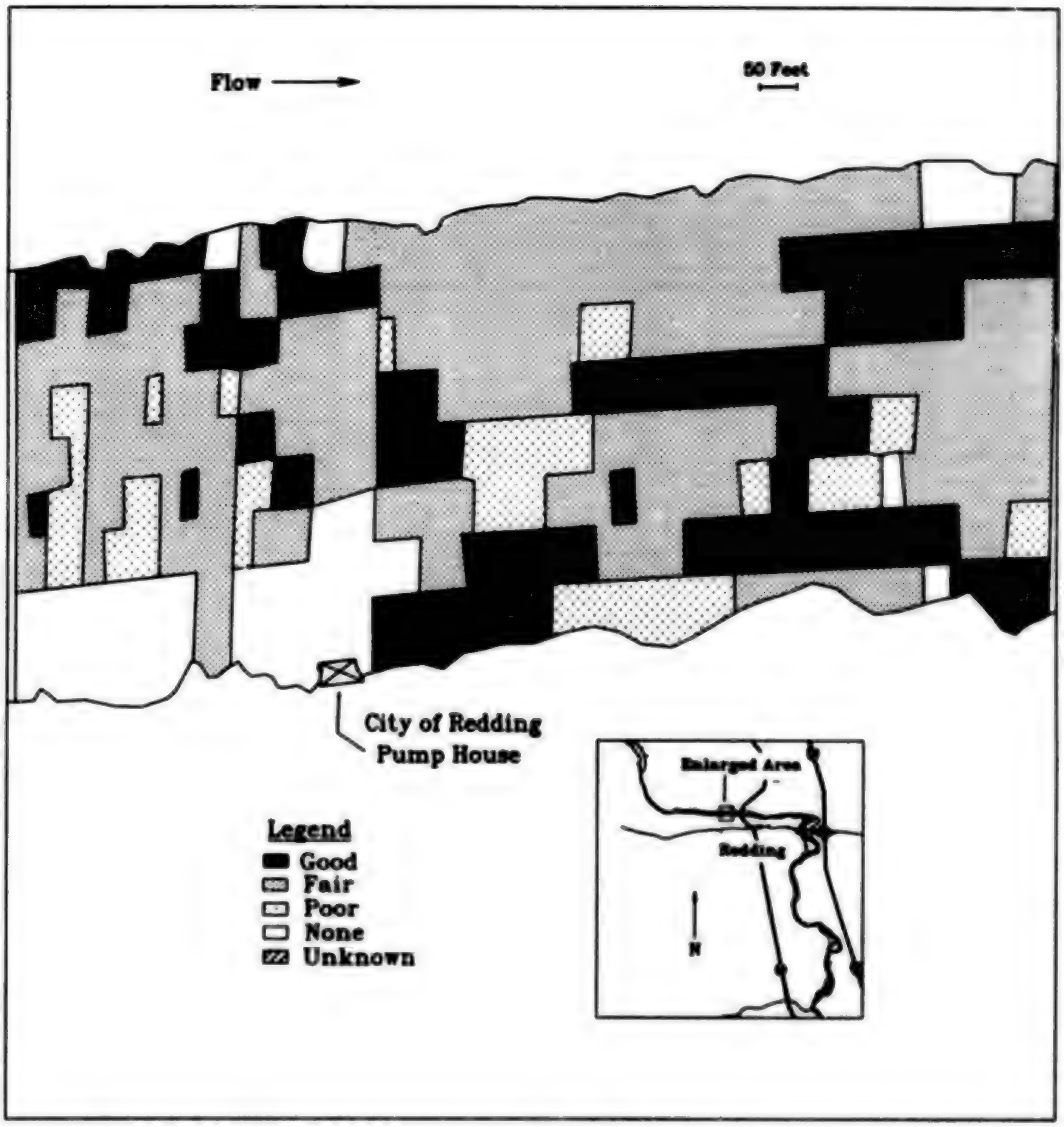
Substrate Maps
Anderson-Cottonwood Diversion to Keswick Dams



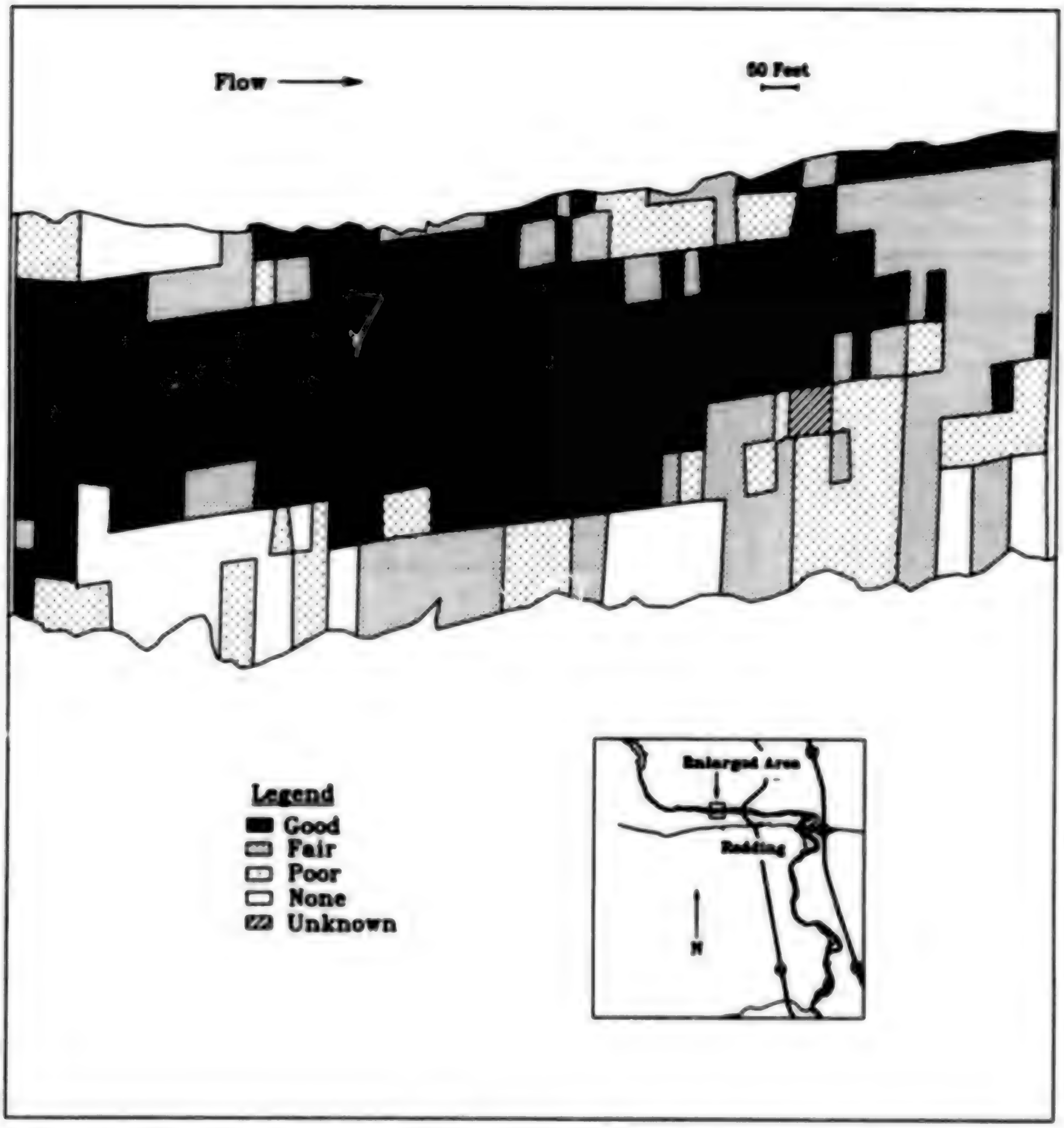
Appendix 26a.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 1 of 14).



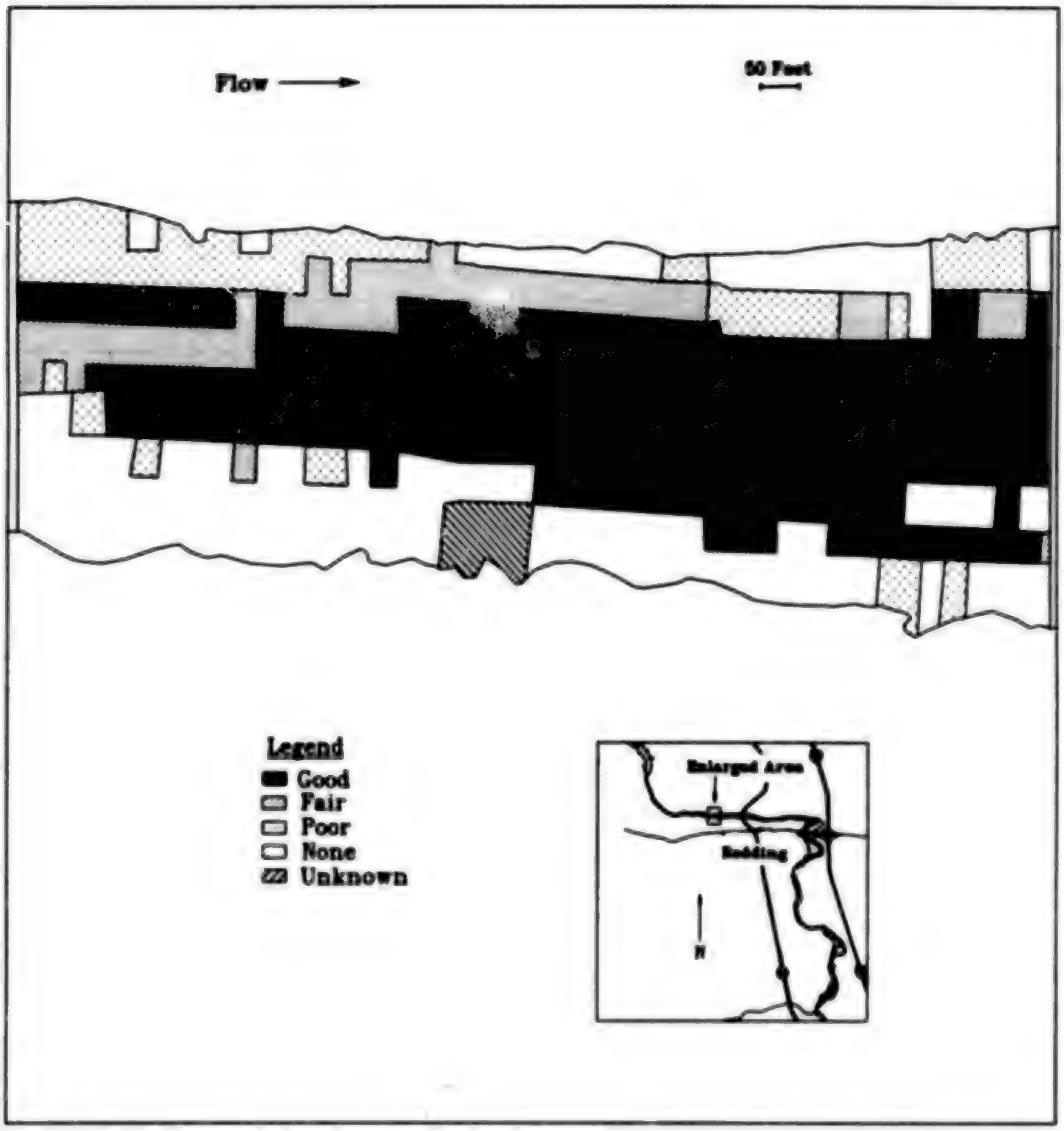
Appendix 26b.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 2 of 14).



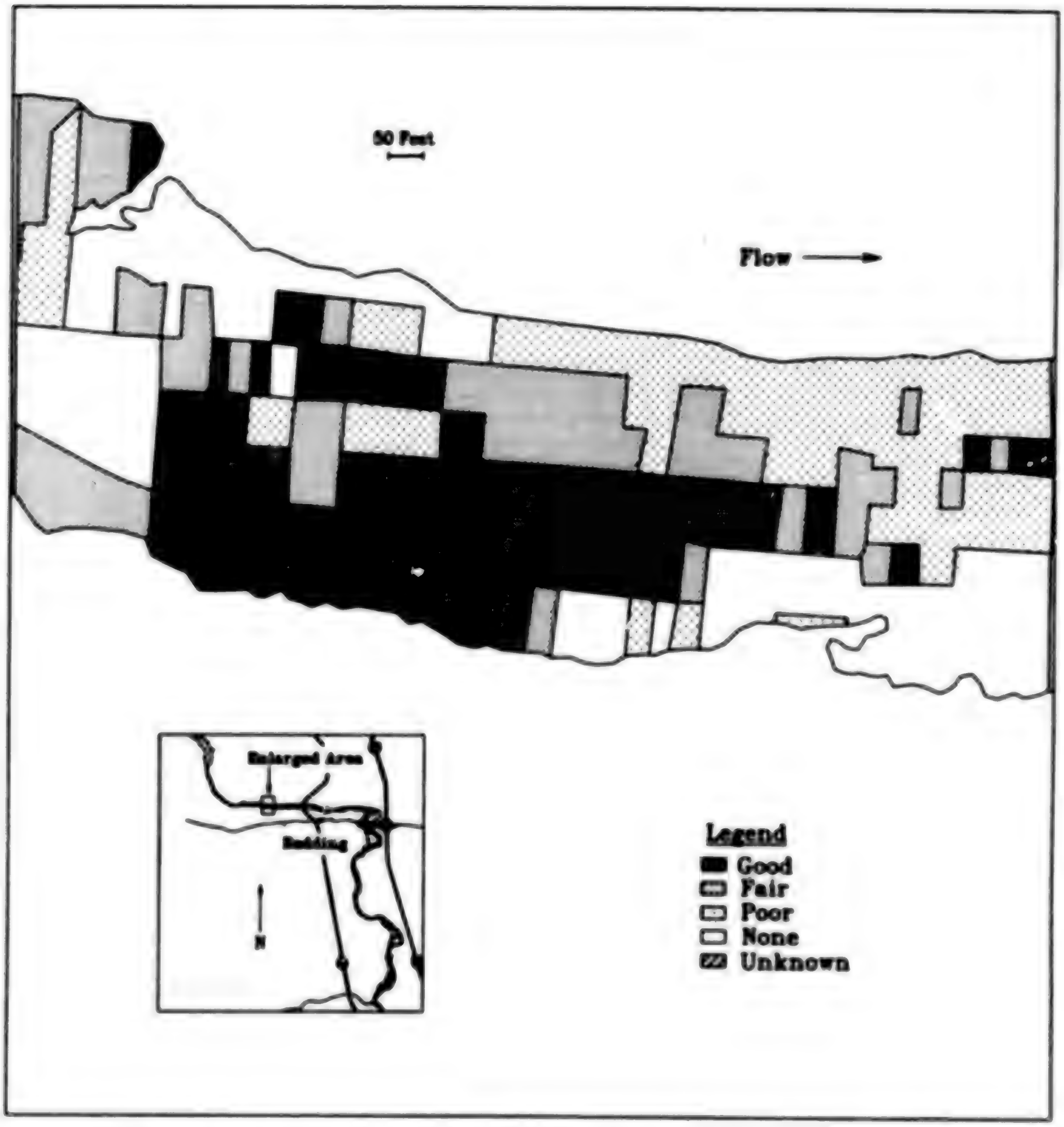
Appendix 26c.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 3 of 14).



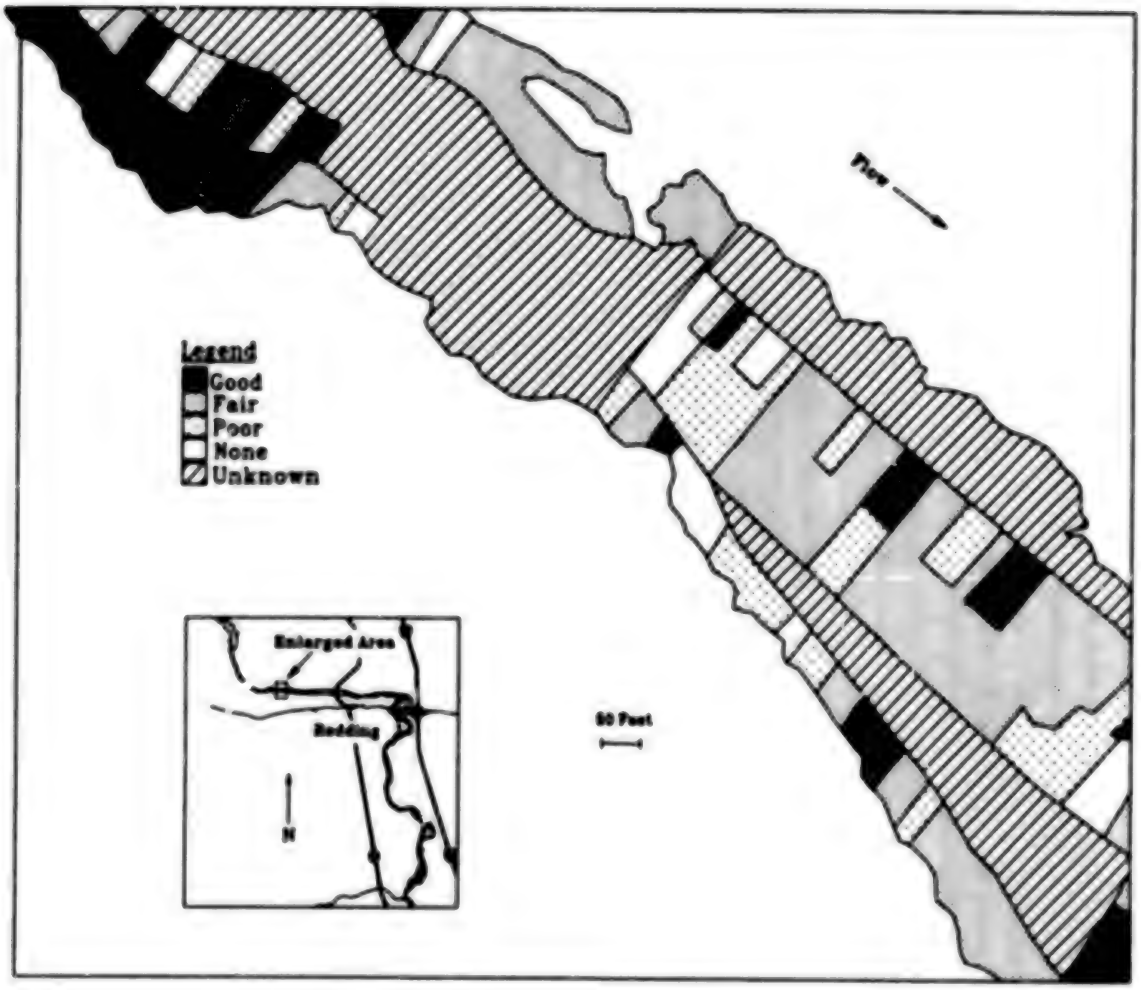
Appendix 26d.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 4 of 14).



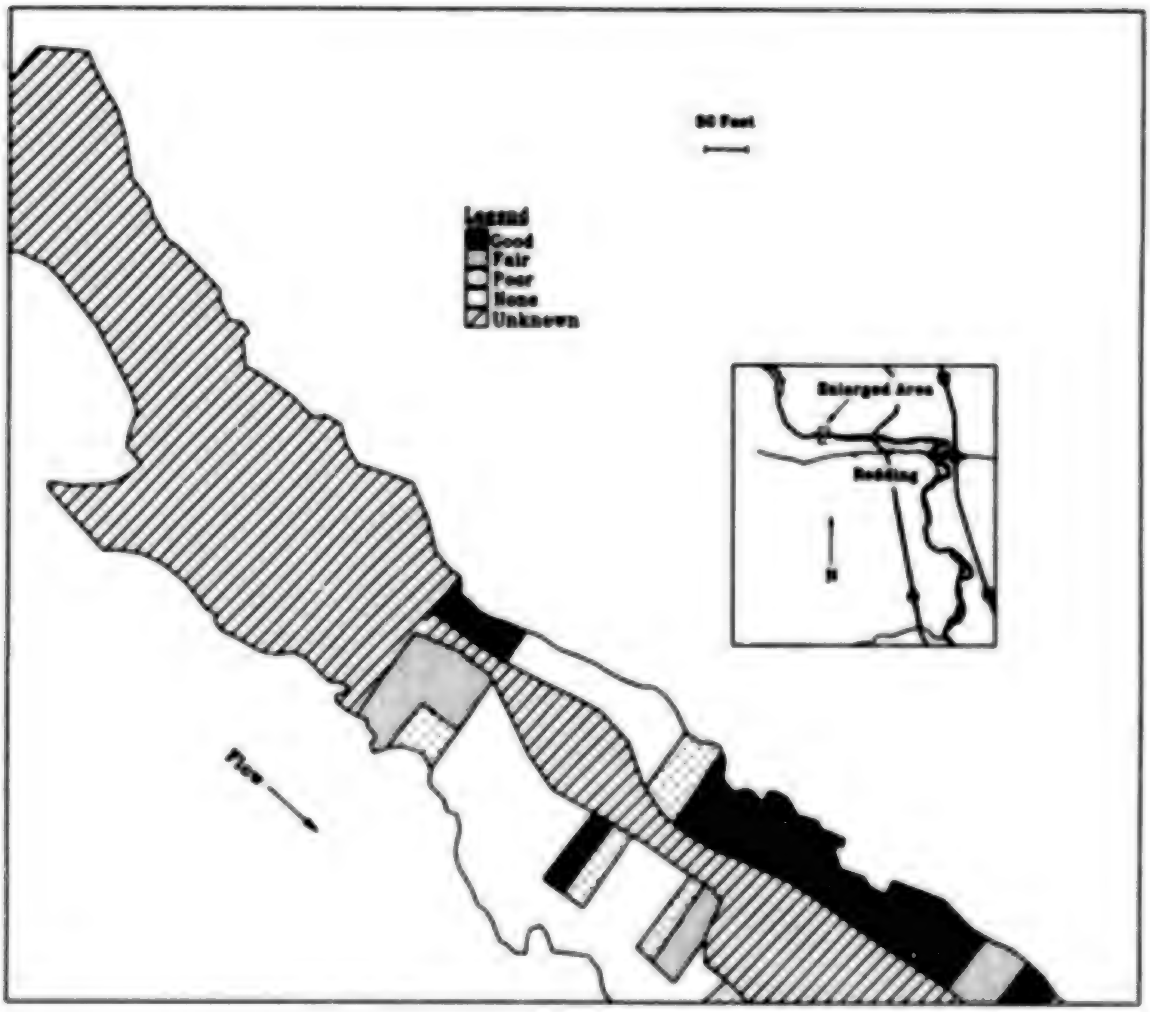
Appendix 26e.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 5 of 14).



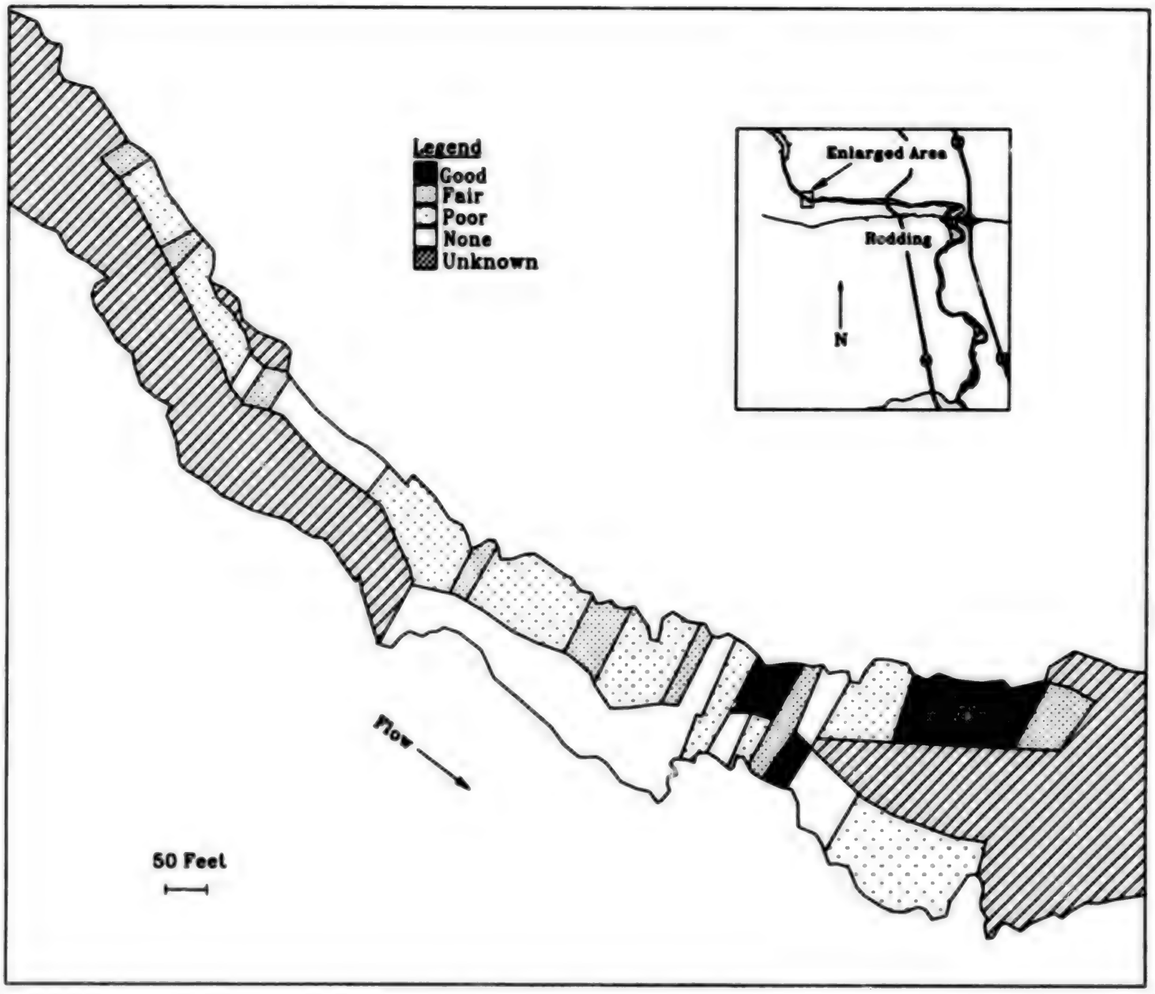
Appendix 26f.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 6 of 14).



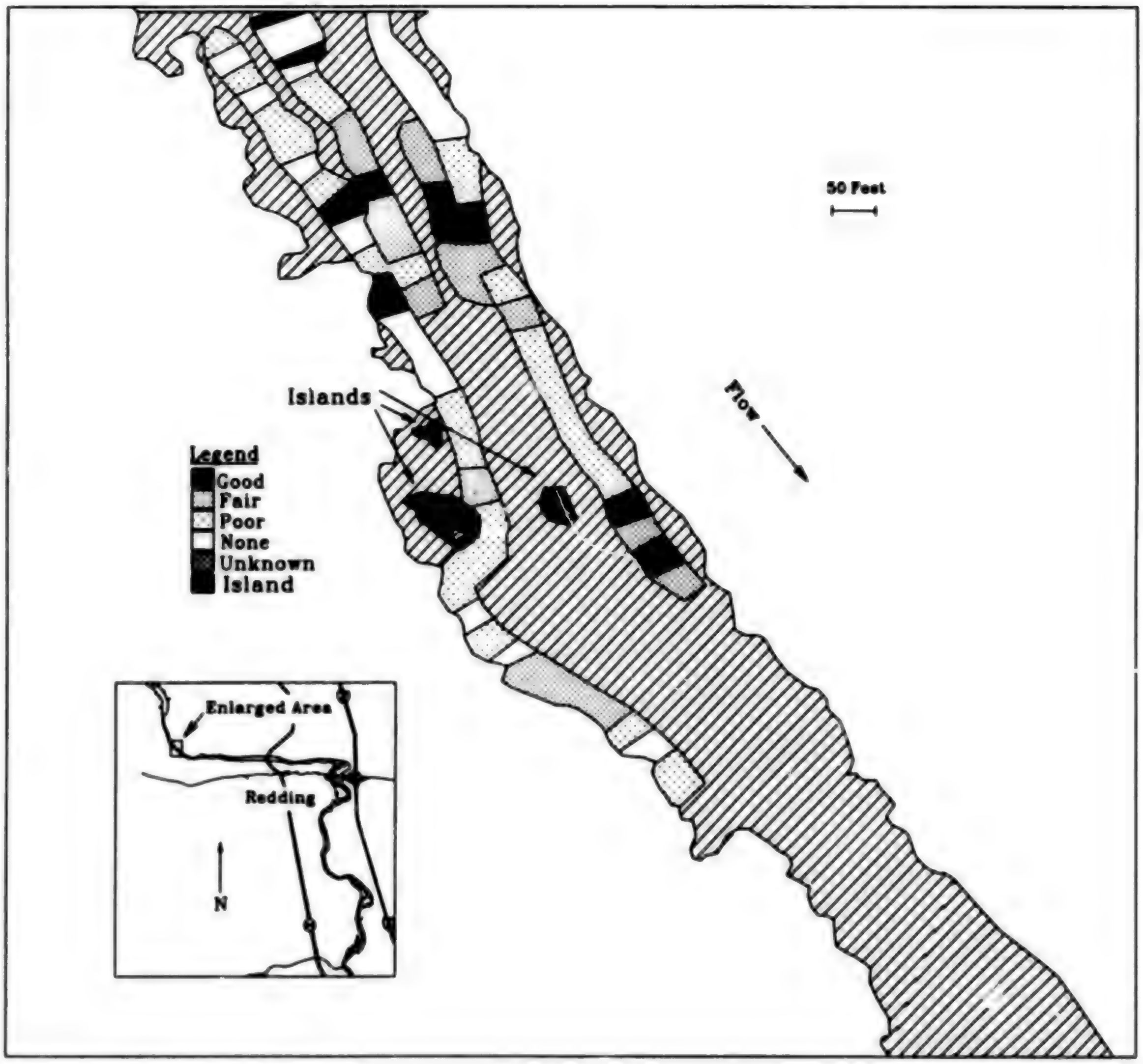
Appendix 26g.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 7 of 14).



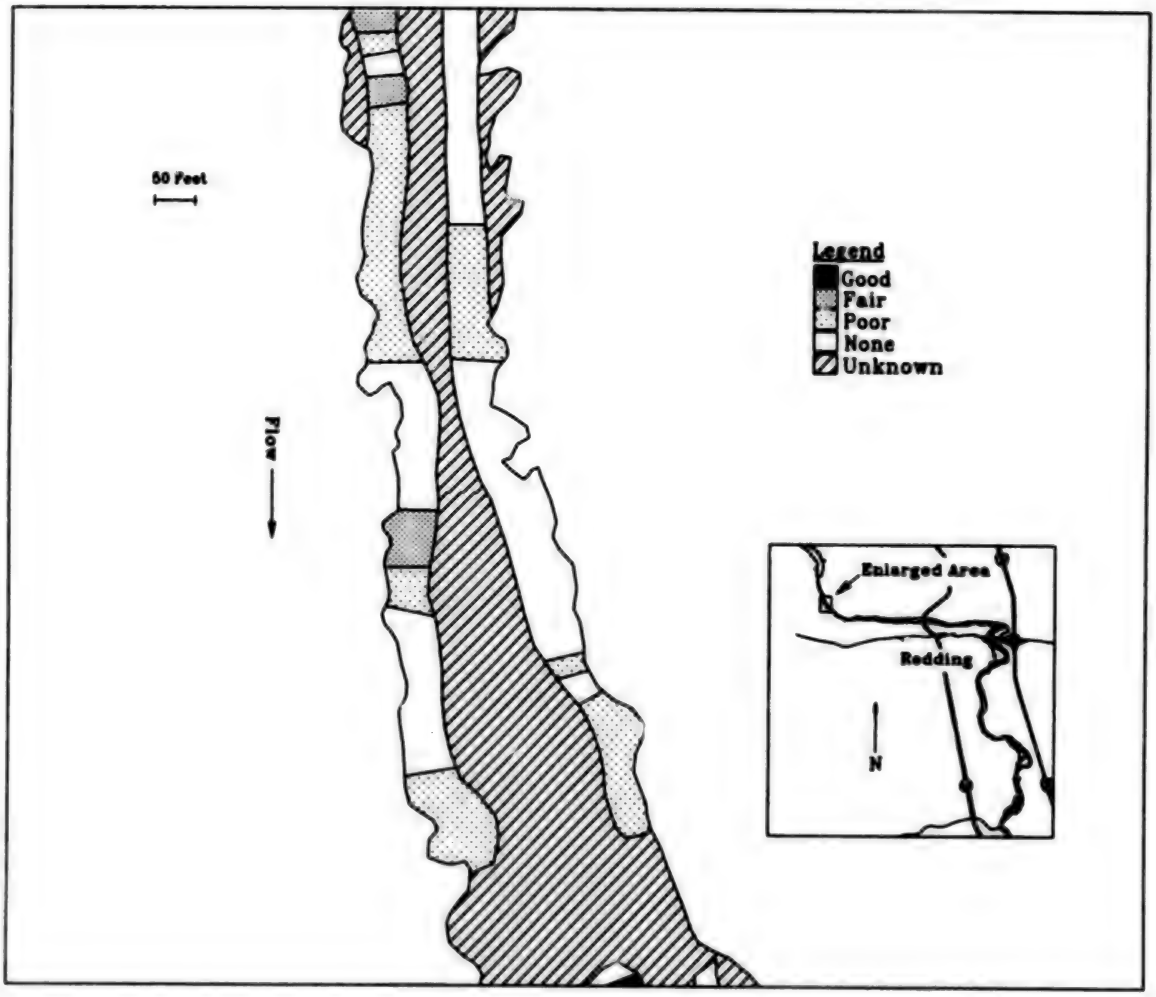
Appendix 26h.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 8 of 14).



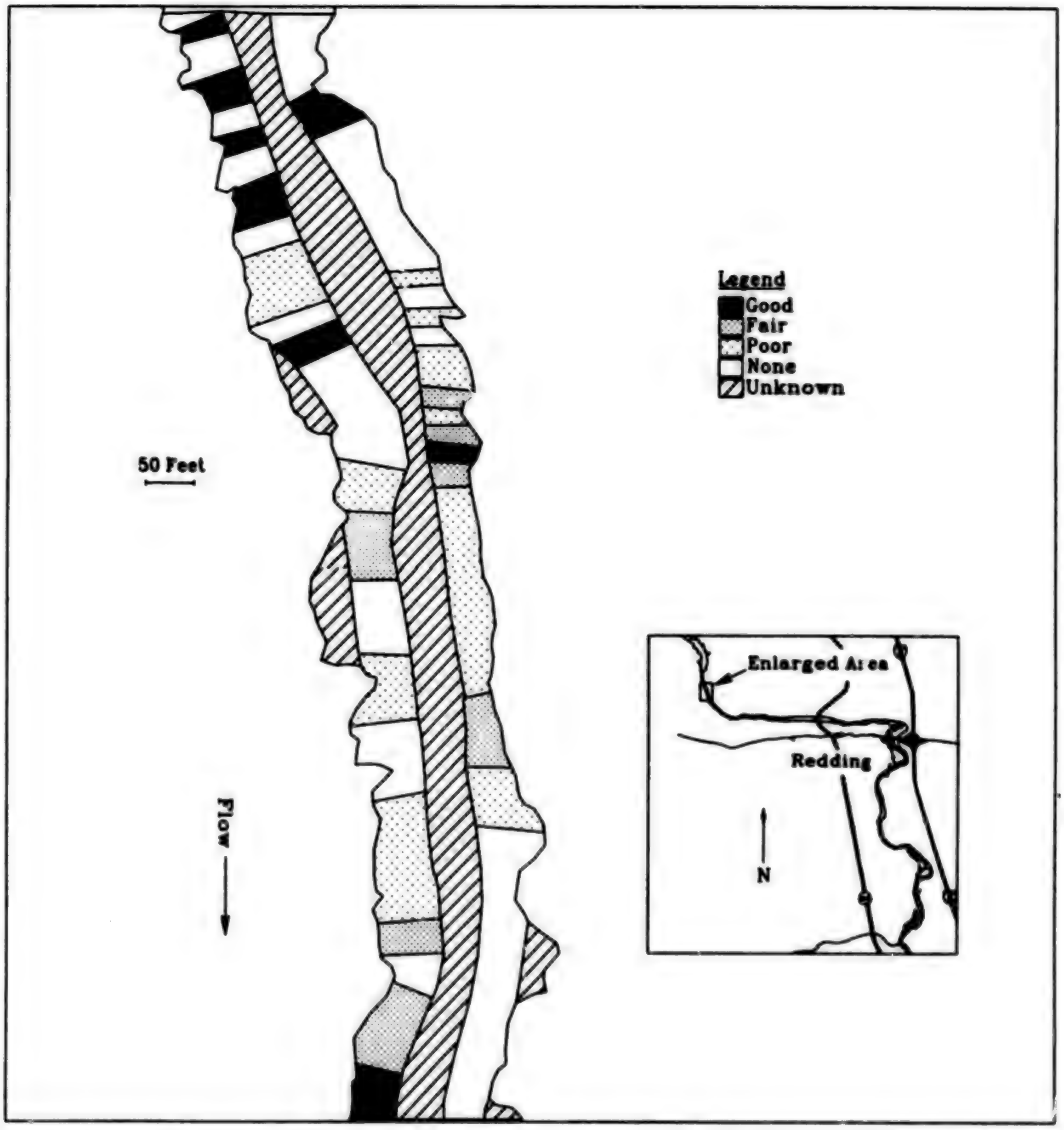
Appendix 26i.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 9 of 14; none of section 10 was surveyed and is, therefore, not presented).



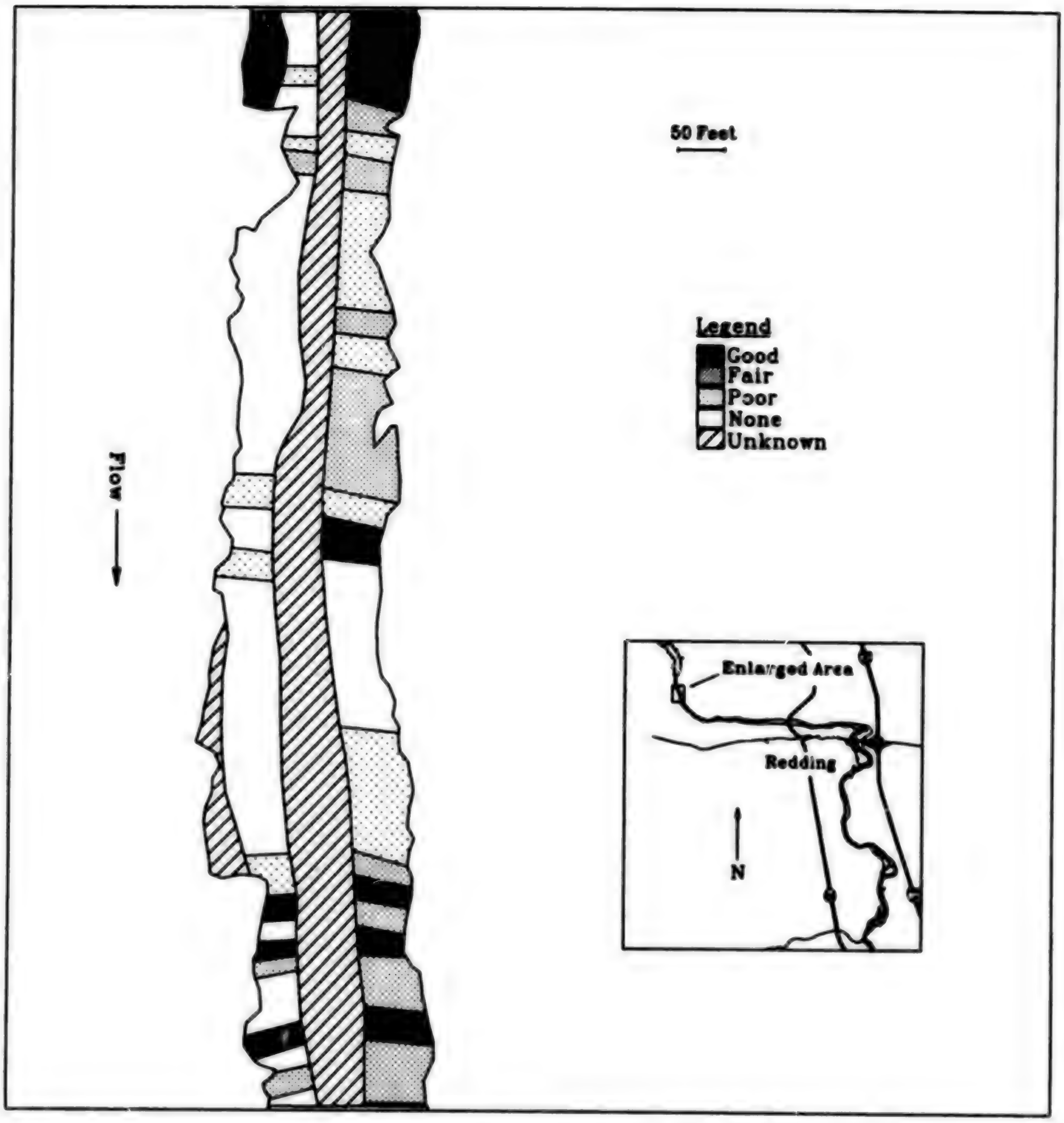
Appendix 26j.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 11 of 15; none of section 10 was surveyed and is, therefore, is not presented).



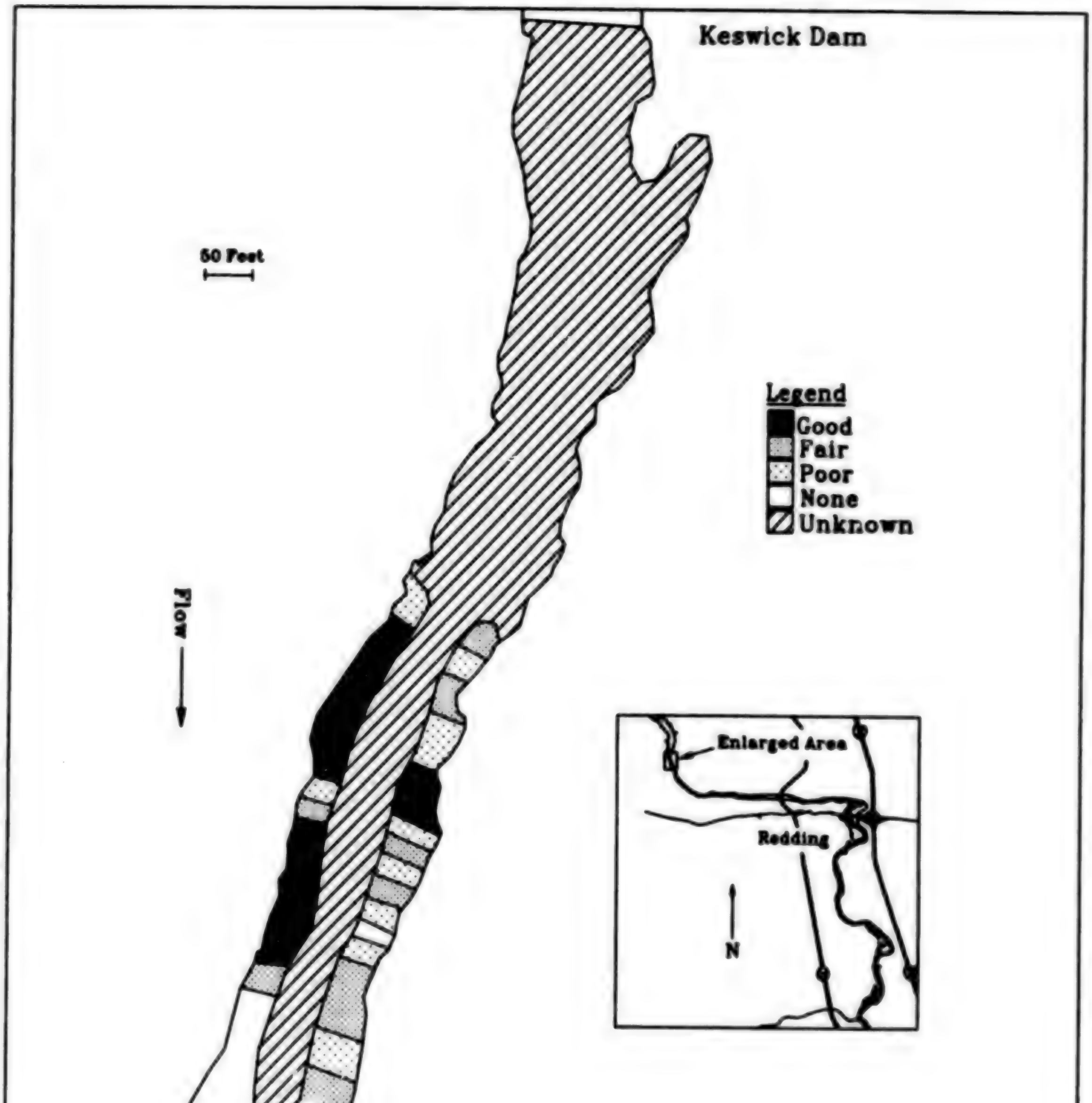
Appendix 26k.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 12 of 15).



Appendix 26I.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 13 of 15).



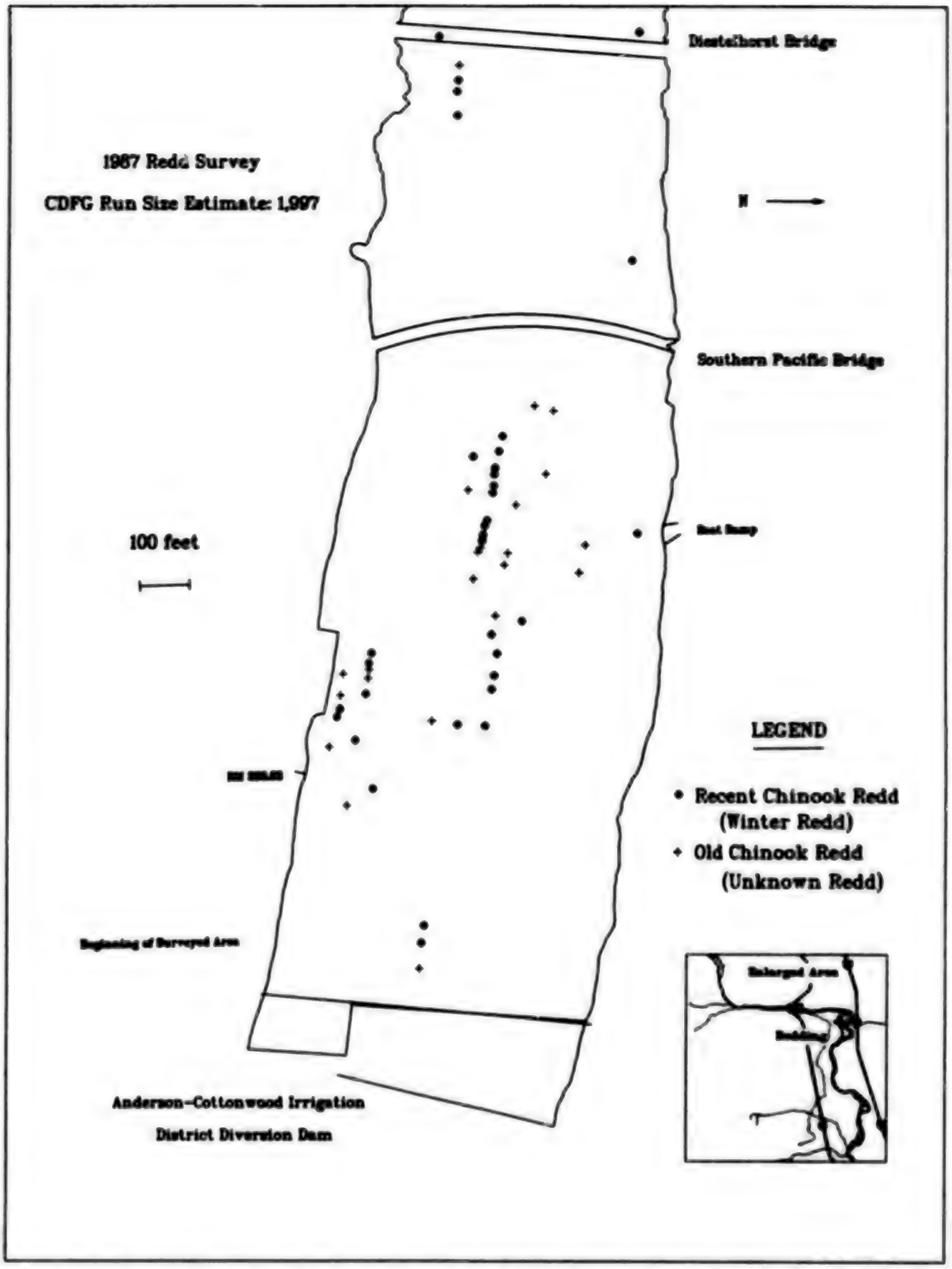
Appendix 26m.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 14 of 15).



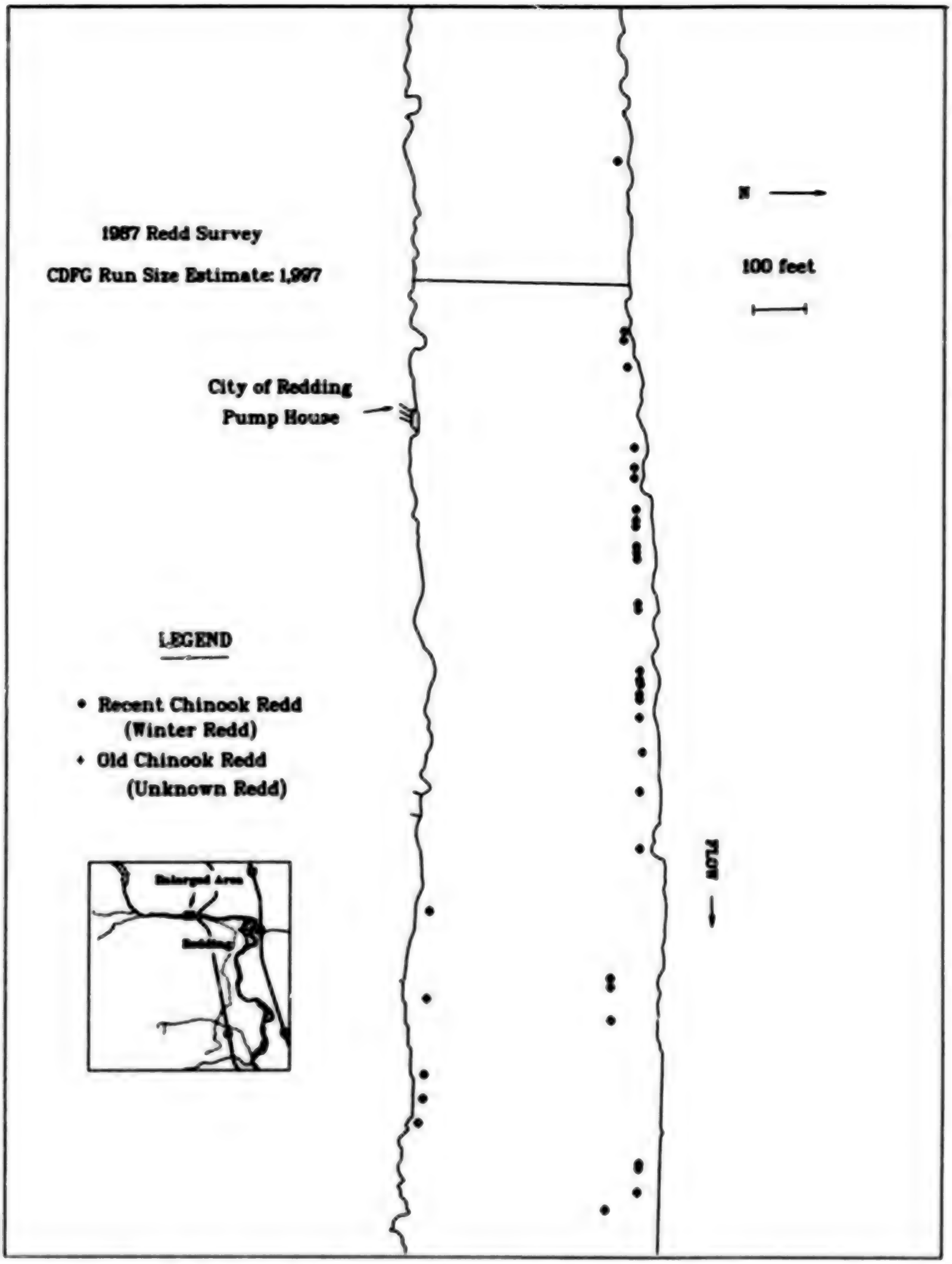
Appendix 26n.—Spawning suitability substrate map for the Sacramento River, Anderson-Cottonwood Irrigation District Dam to Keswick Dam, 1993 (section 15 of 15).

Appendix I

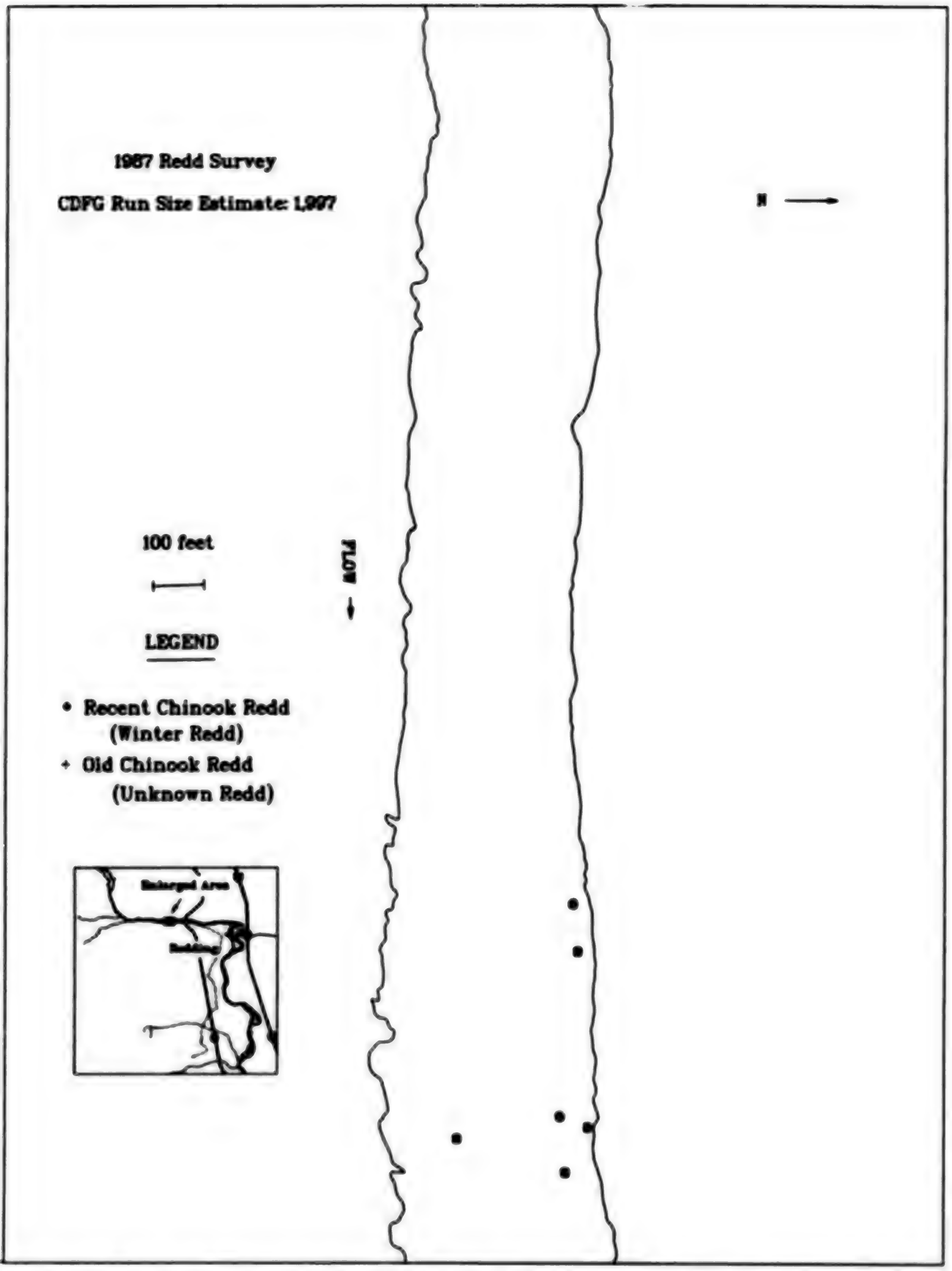
Location of Winter-Run Chinook Salmon Redds as Determined by SCUBA Observations During July 1987-1993


Diestelhorst Bridge
1987 Redd Survey
CDFG Run Size Estimate: 1,997
N
Southern Pacific Bridge
100 feet
Boat Ramp
LEGEND
• Recent Chinook Redd (Winter Redd)
✦ Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson-Cottonwood Irrigation District Diversion Dam

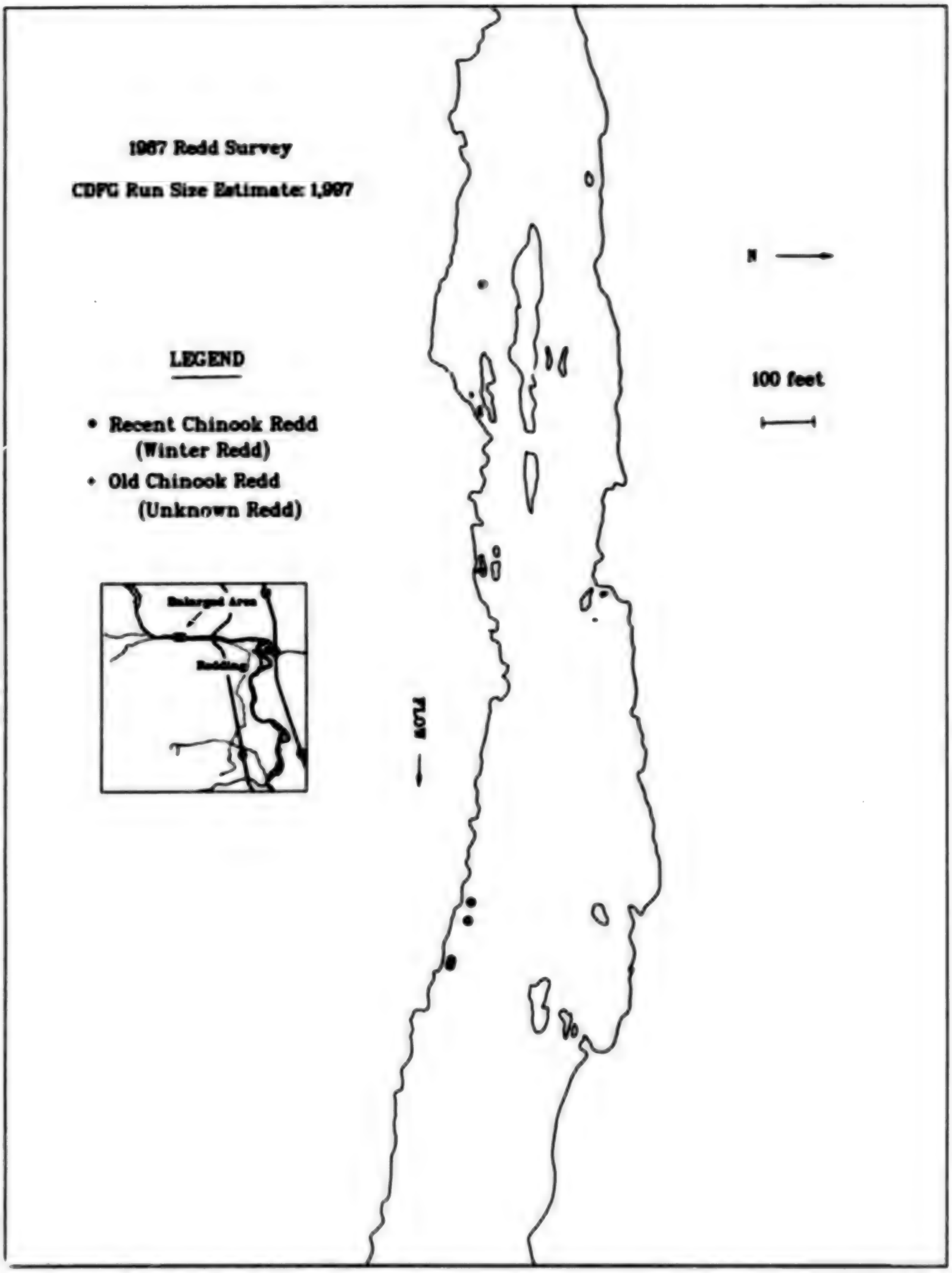
Appendix 27a.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1987, section 1 of 9. (Map sections where no redds were located are not included in the Appendices).



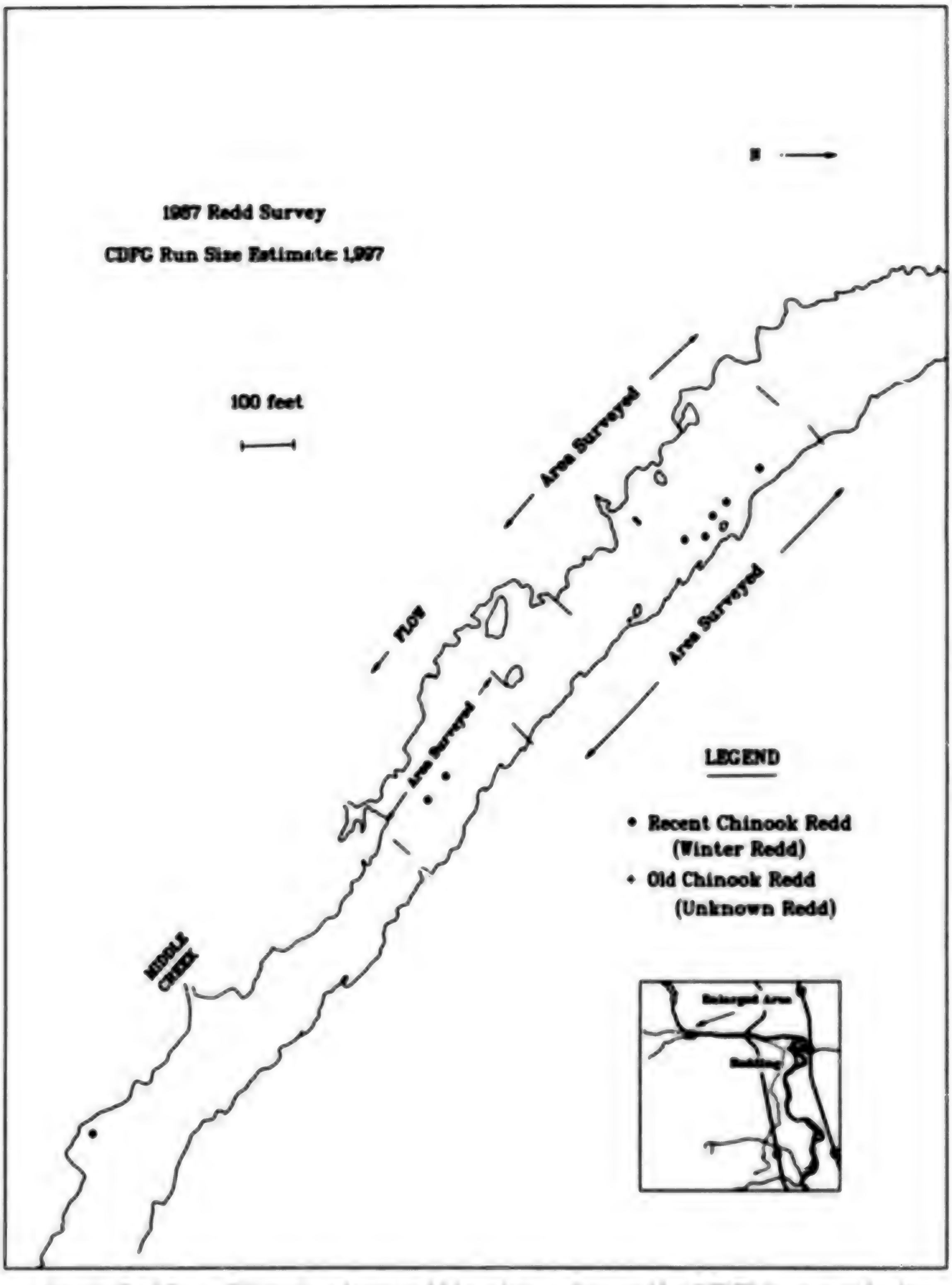
Appendix 27b.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1987, section 2 of 9.


1987 Redd Survey
CDFG Run Size Estimate: 1,997
N
100 feet
FLOW
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding

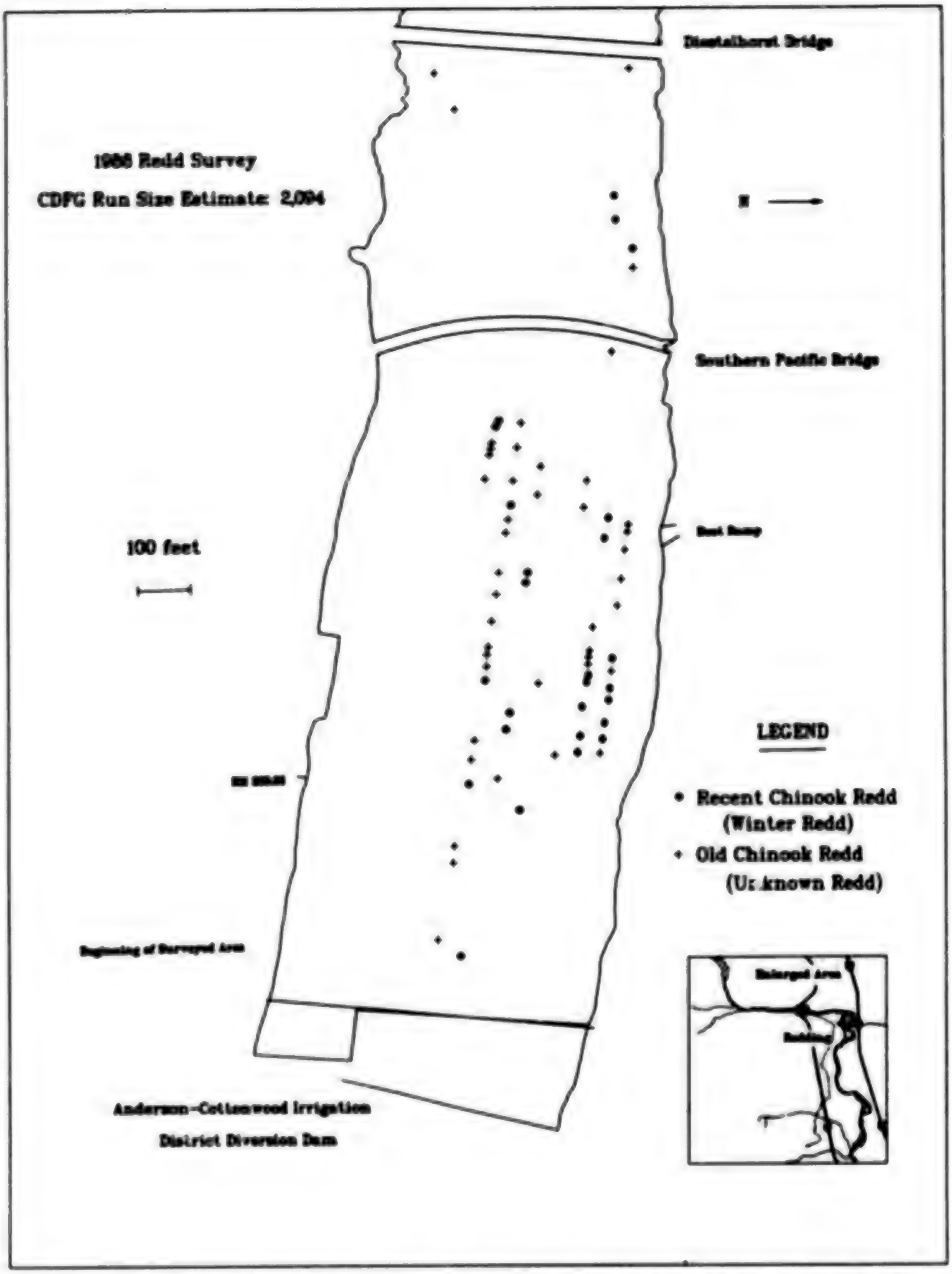
Appendix 27c.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1987, section 3 of 9.


1987 Redd Survey
CDFG Run Size Estimate: 1,997
N
100 feet
LEGEND
● Recent Chinook Redd (Winter Redd)
• Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding
FLOW

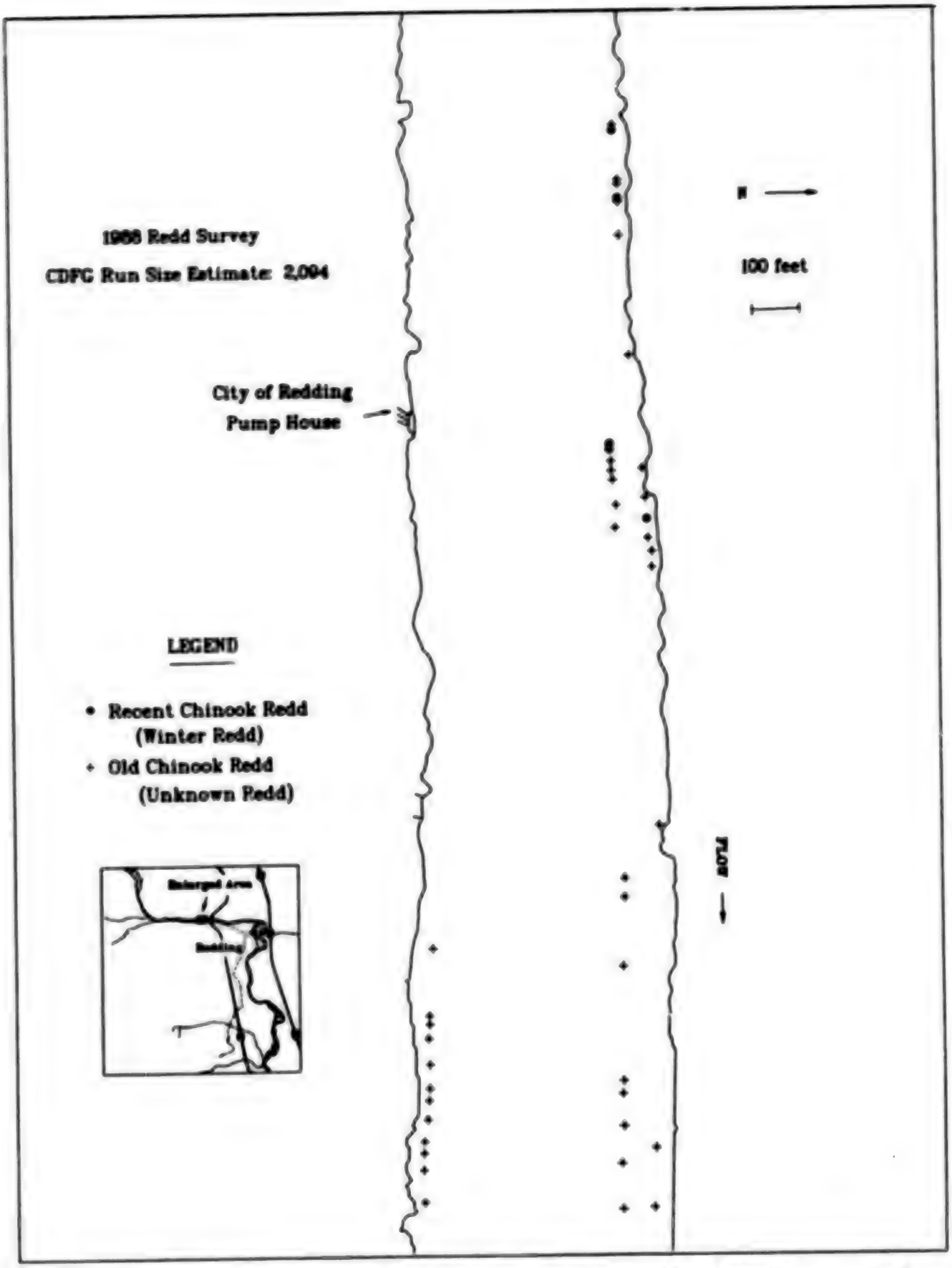
ppendix 27d.—Chinook salmon redd locations, observed by SCUBA survey, in the amento River from ACID to Keswick dams, 1987, section 4 of 9.



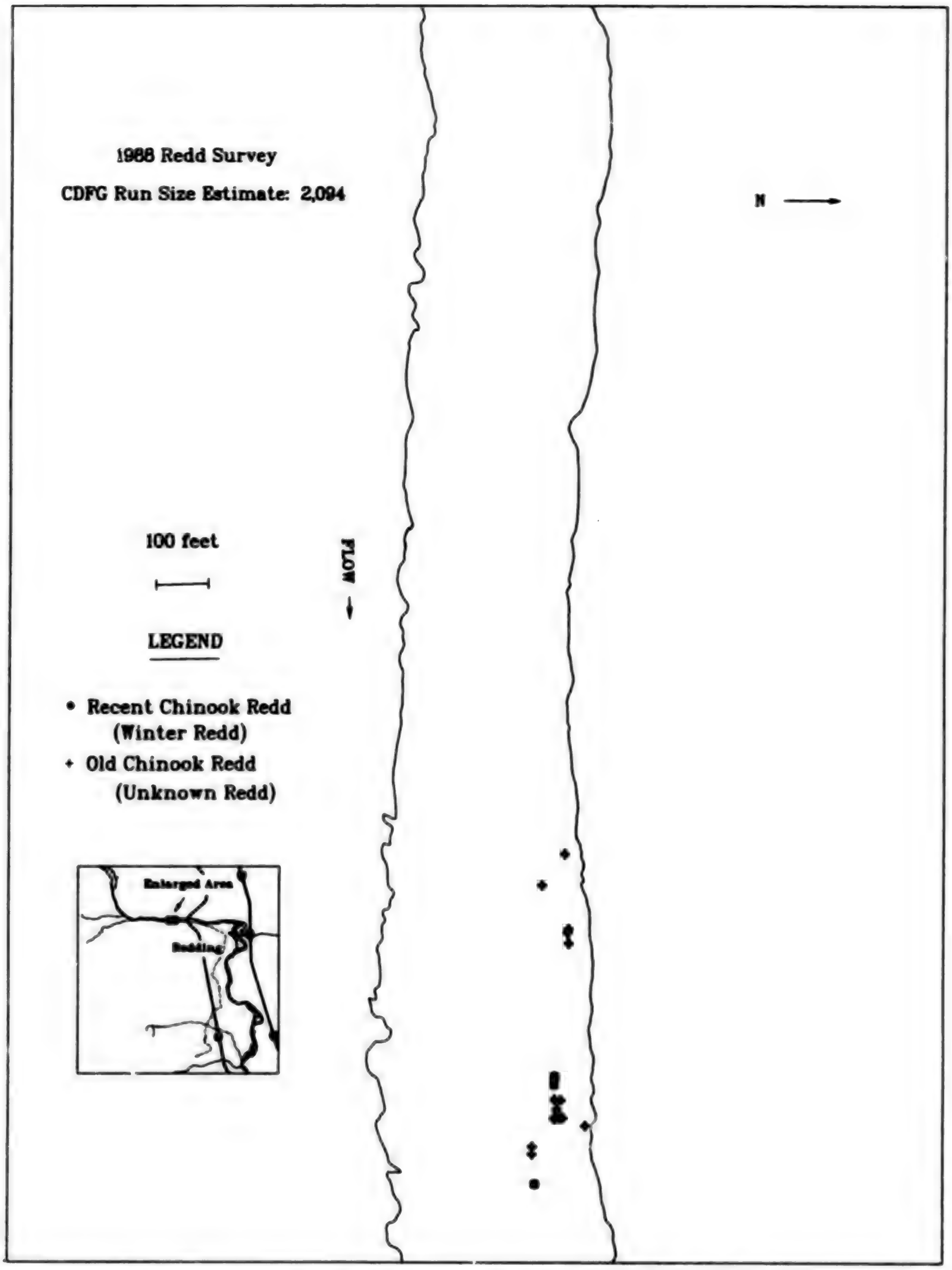
Appendix 27e.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1987, section 6 of 9.


Diestelhorst Bridge
1988 Redd Survey
CDFG Run Size Estimate: 2,094
N
Southern Pacific Bridge
Boat Ramp
100 feet
LEGEND
● Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson-Cottonwood Irrigation District Diversion Dam

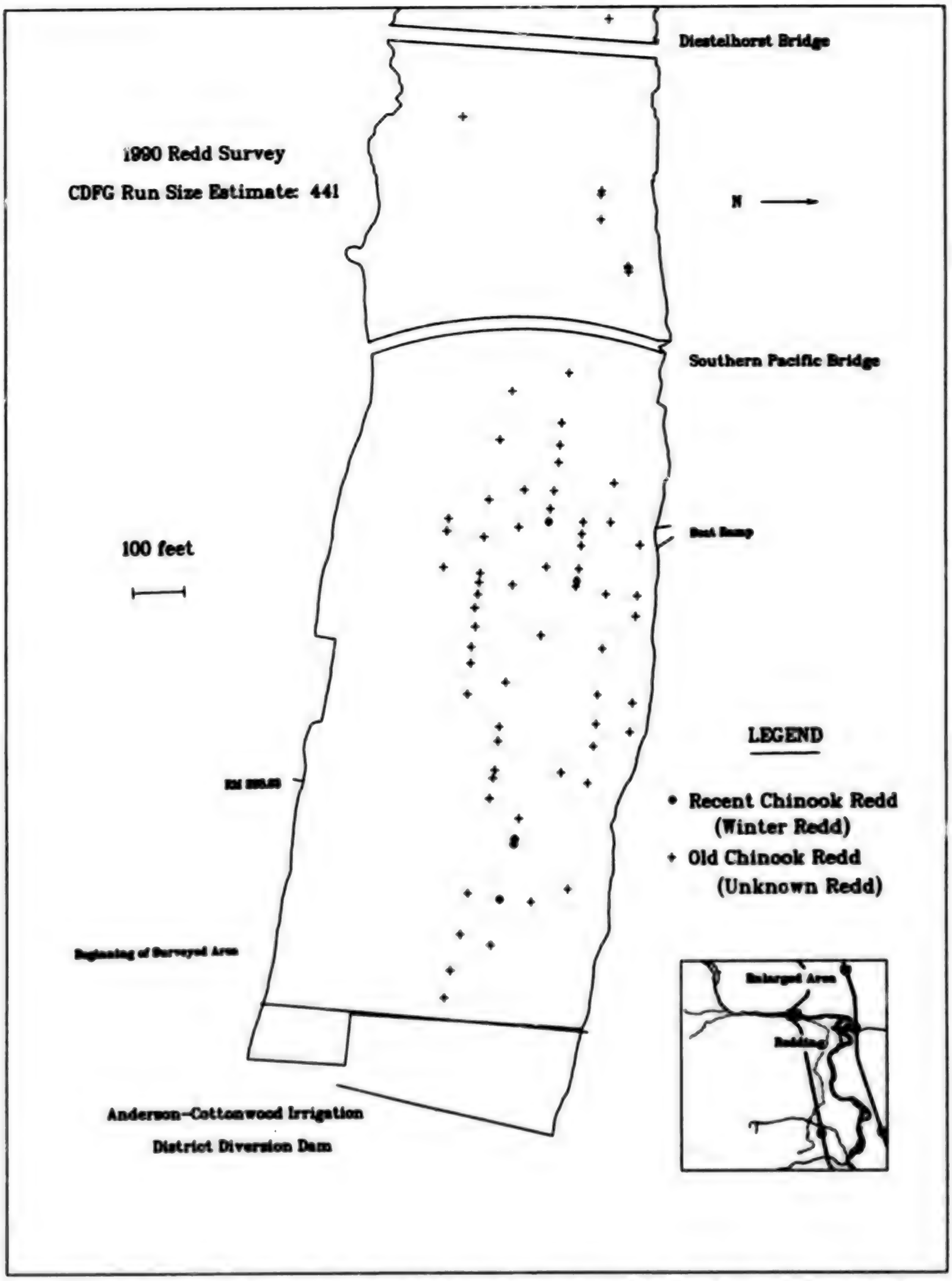
Appendix 28a.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1988, section 1 of 3.


1988 Redd Survey
CDFG Run Size Estimate: 2,094
N
100 feet
City of Redding
Pump House
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
FLOW
Enlarged Area
Redding

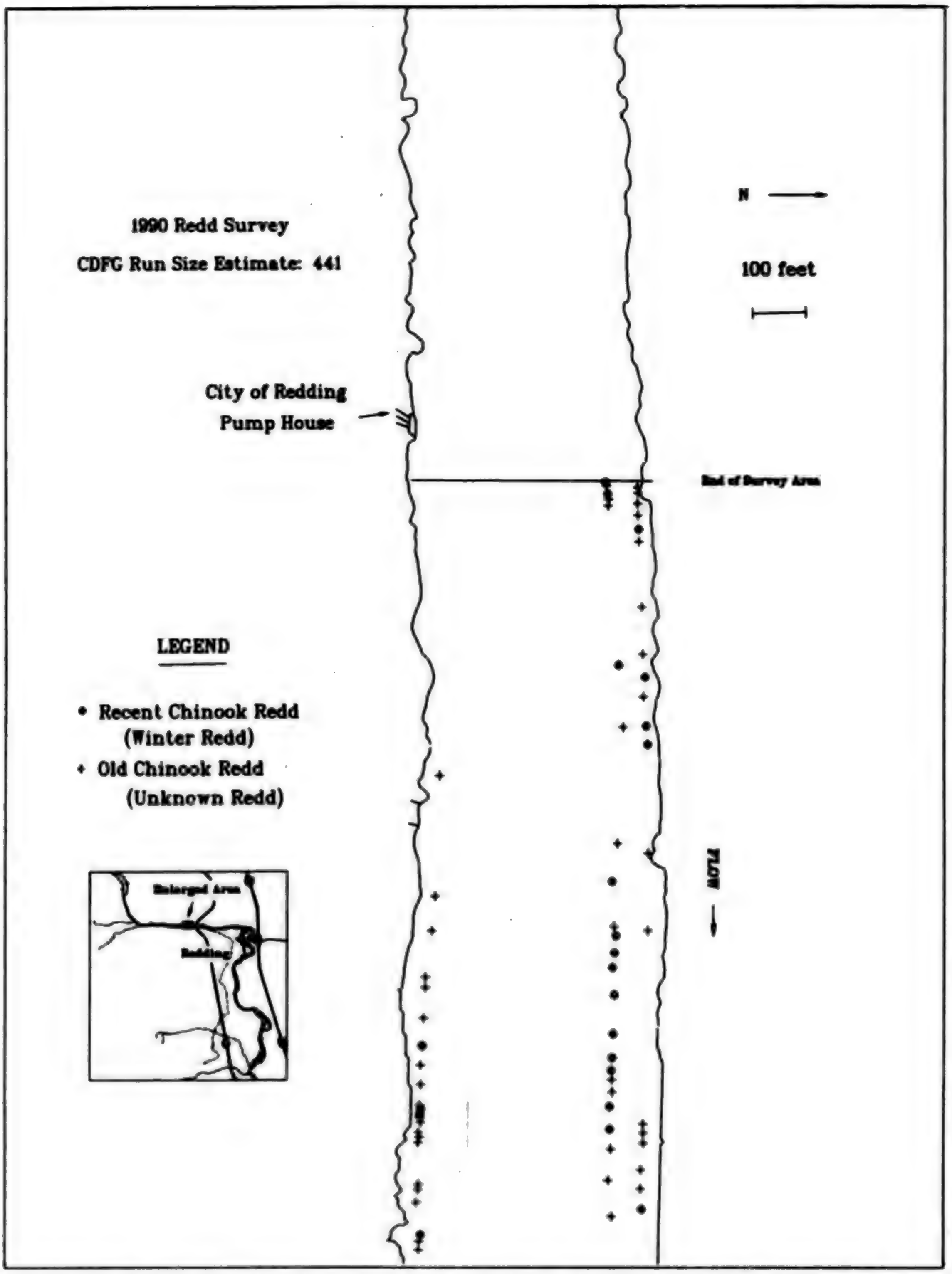
Appendix 28b.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1988, section 2 of 3.


1988 Redd Survey
CDFG Run Size Estimate: 2,094
N
100 feet
FLOW
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding

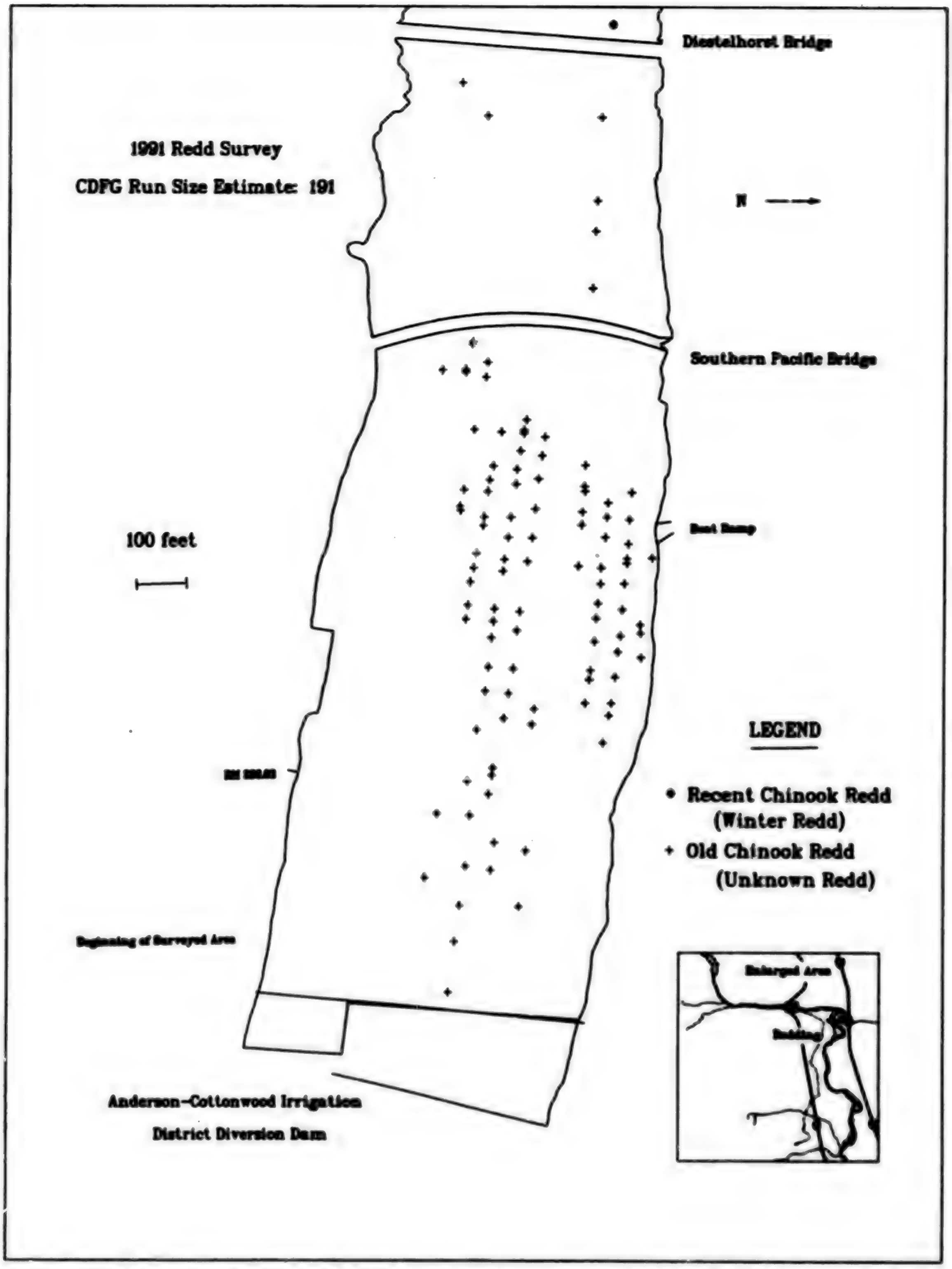
Appendix 28c.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1988, section 3 of 3.


Diestelhorst Bridge
1990 Redd Survey
CDFG Run Size Estimate: 441
N
Southern Pacific Bridge
Boat Ramp
100 feet
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson–Cottonwood Irrigation District Diversion Dam

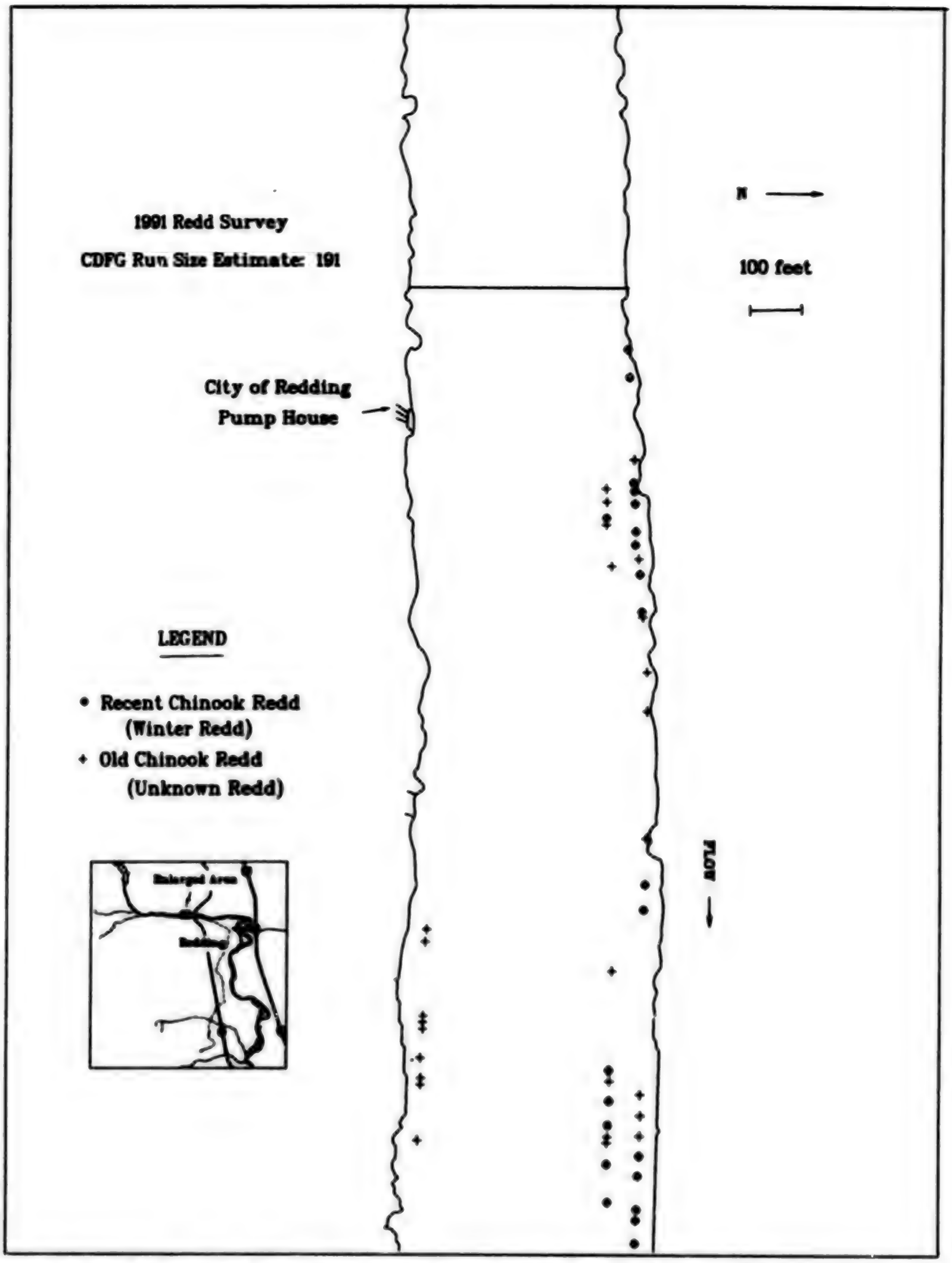
Appendix 29a.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1990, section 1 of 2.



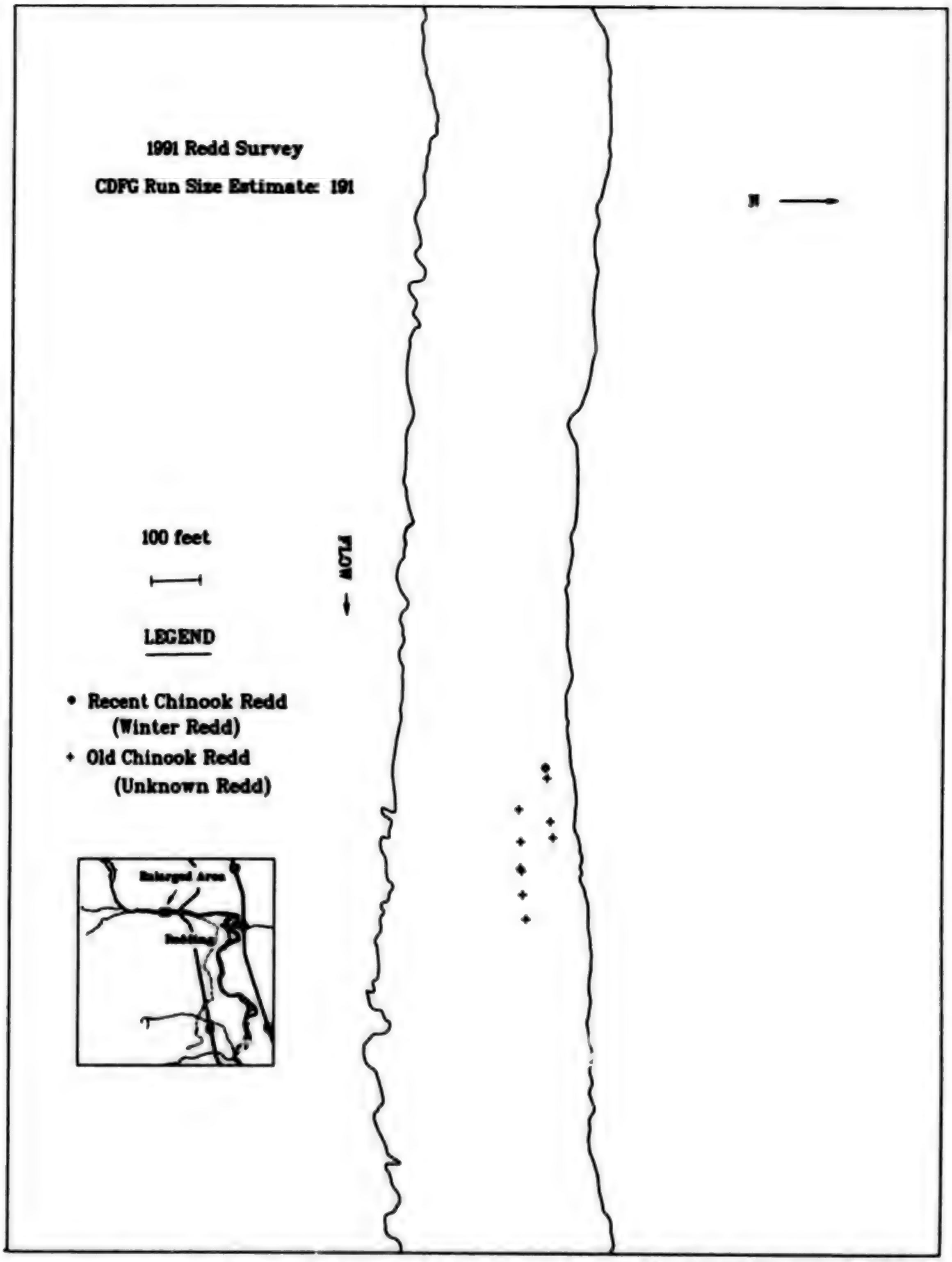
Appendix 29b.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1990, section 2 of 2.


Diestelhorst Bridge
1991 Redd Survey
CDFG Run Size Estimate: 191
N
Southern Pacific Bridge
Boat Ramp
100 feet
LEGEND
● Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson-Cottonwood Irrigation District Diversion Dam

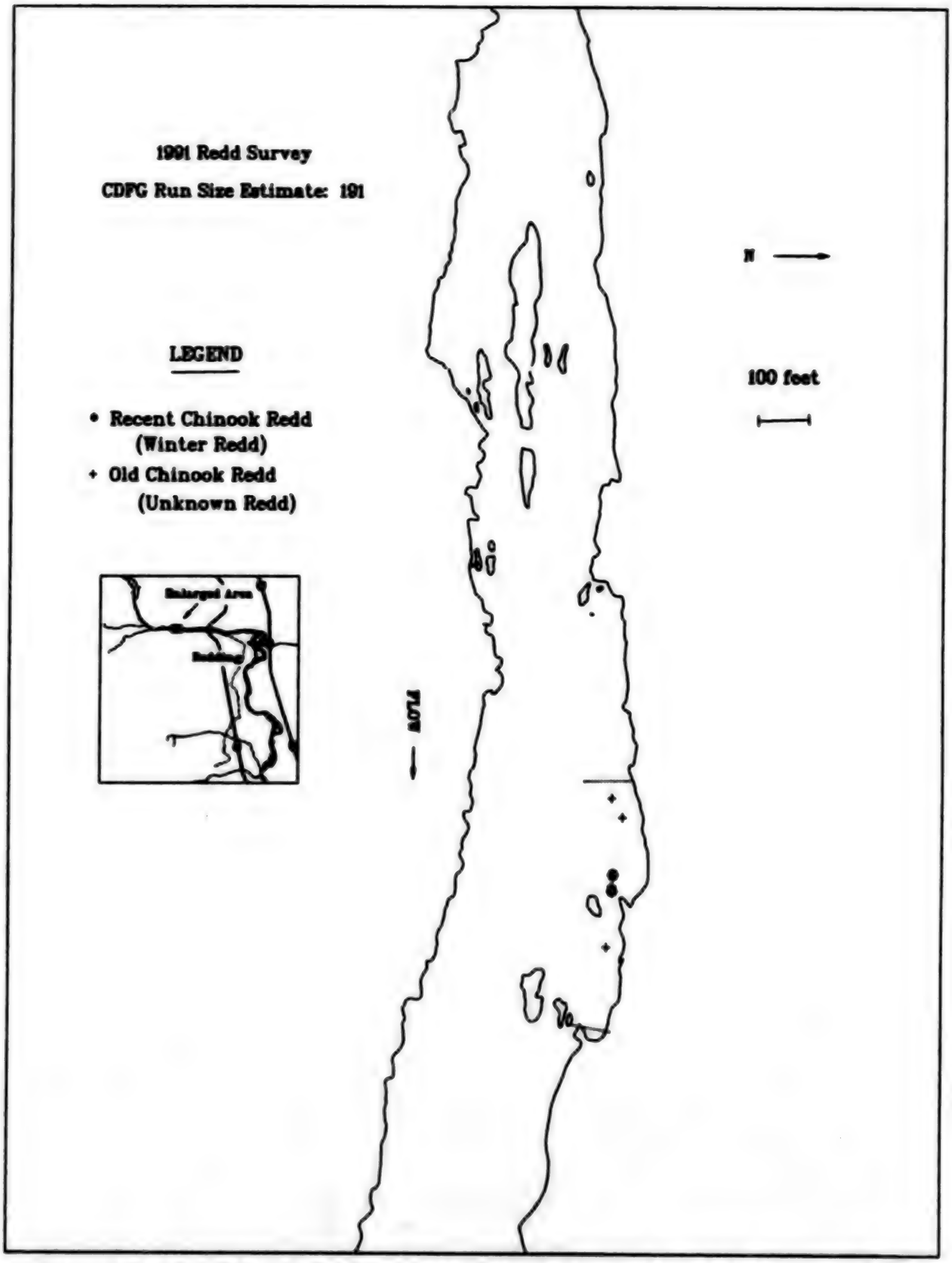
Appendix 30a.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1991, section 1 of 4.


1991 Redd Survey
CDFG Run Size Estimate: 191
N
100 feet
City of Redding
Pump House
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding
FLOW

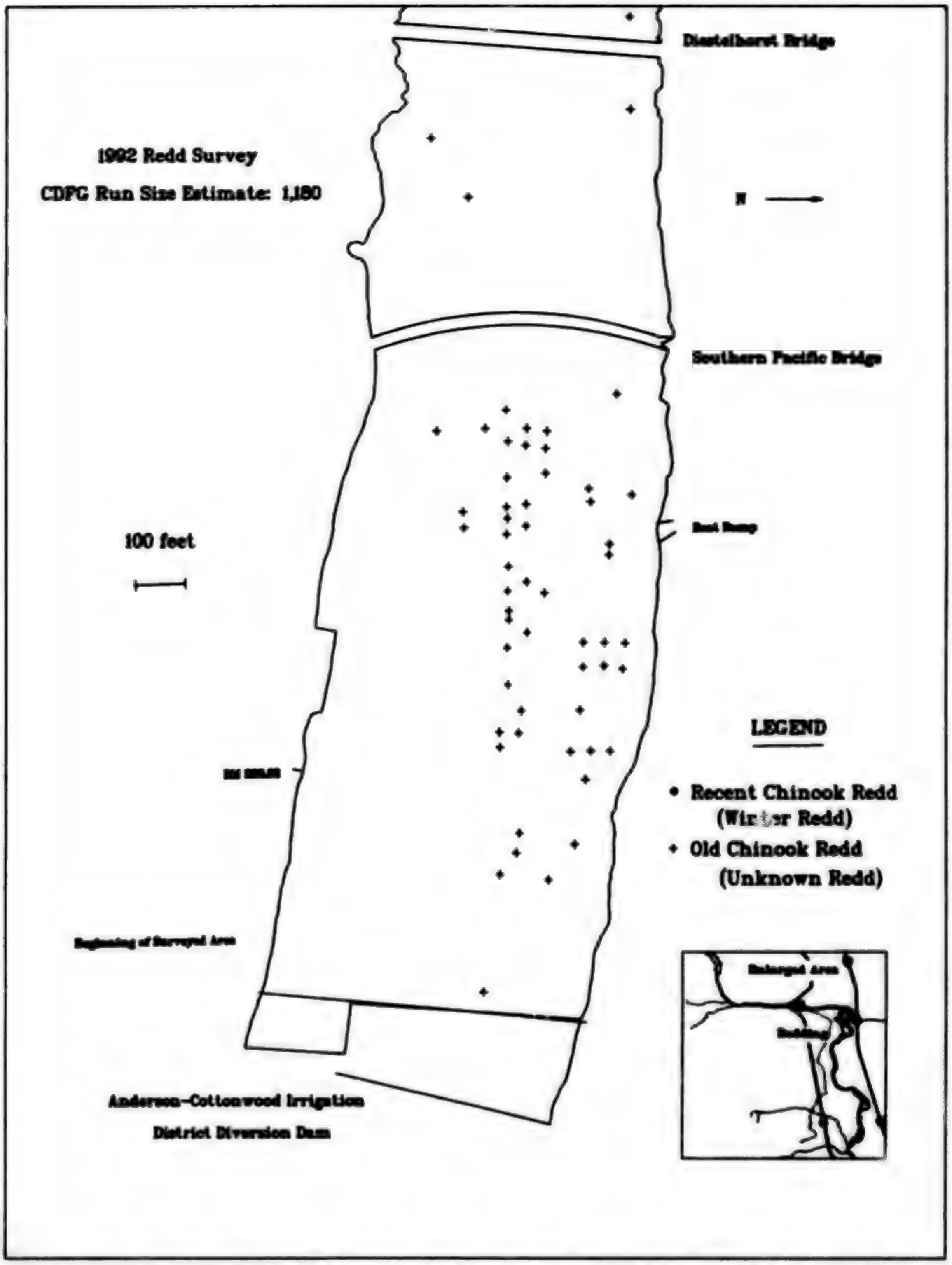
Appendix 30b.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1991, section 2 of 4.


1991 Redd Survey
CDFG Run Size Estimate: 191
N
100 feet
FLOW
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding

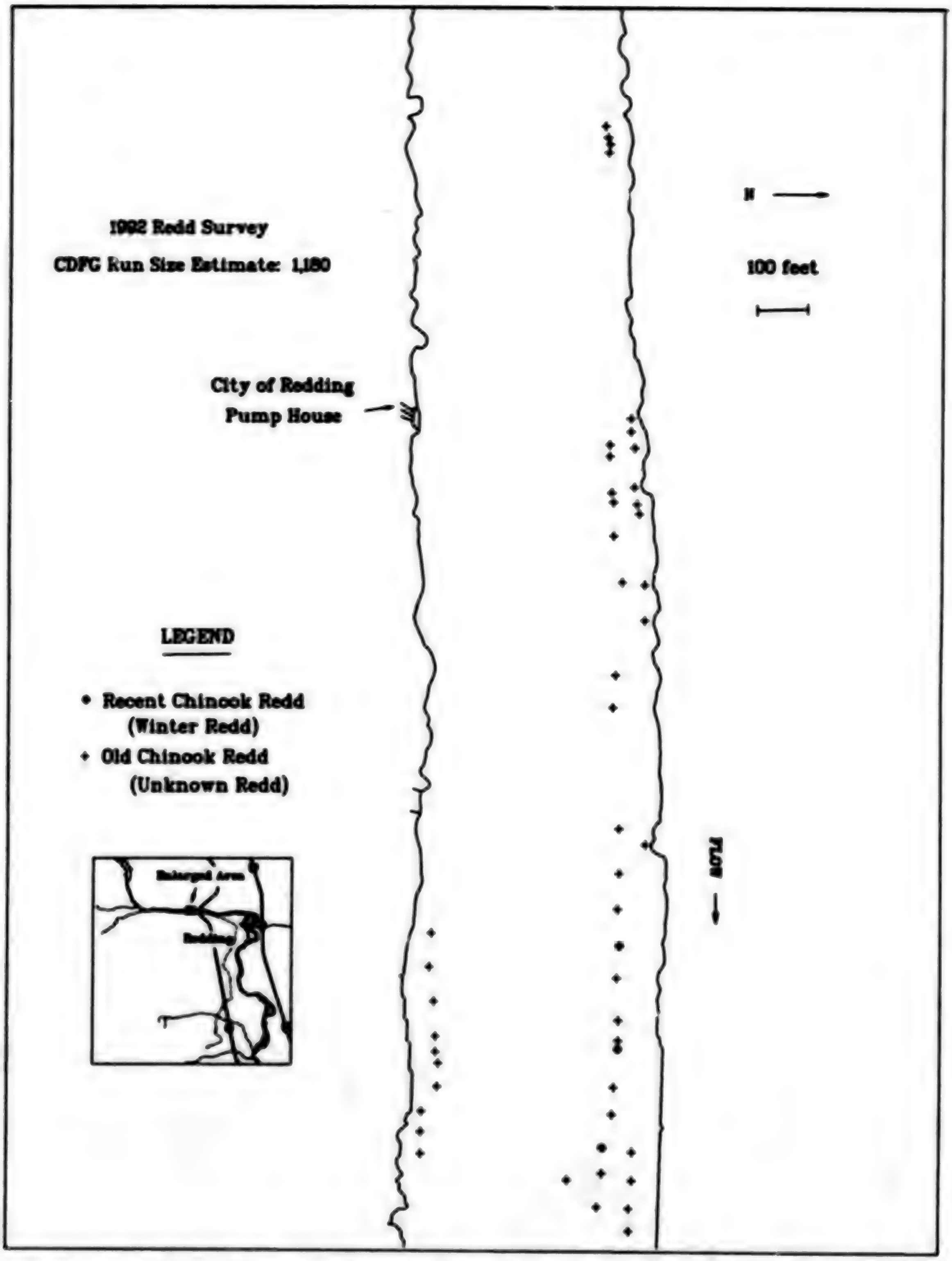
Appendix 30c.—Chinook salmon redd locations, observed by SCUBA survey, in areas of the Sacramento River, 1991, section 3 of 4. Two transects along the north bank of the river were surveyed where chinook redds had been previously observed.


1991 Redd Survey
CDFG Run Size Estimate: 191
N
LEGEND
● Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
100 feet
Enlarged Area
Redding
FLOW

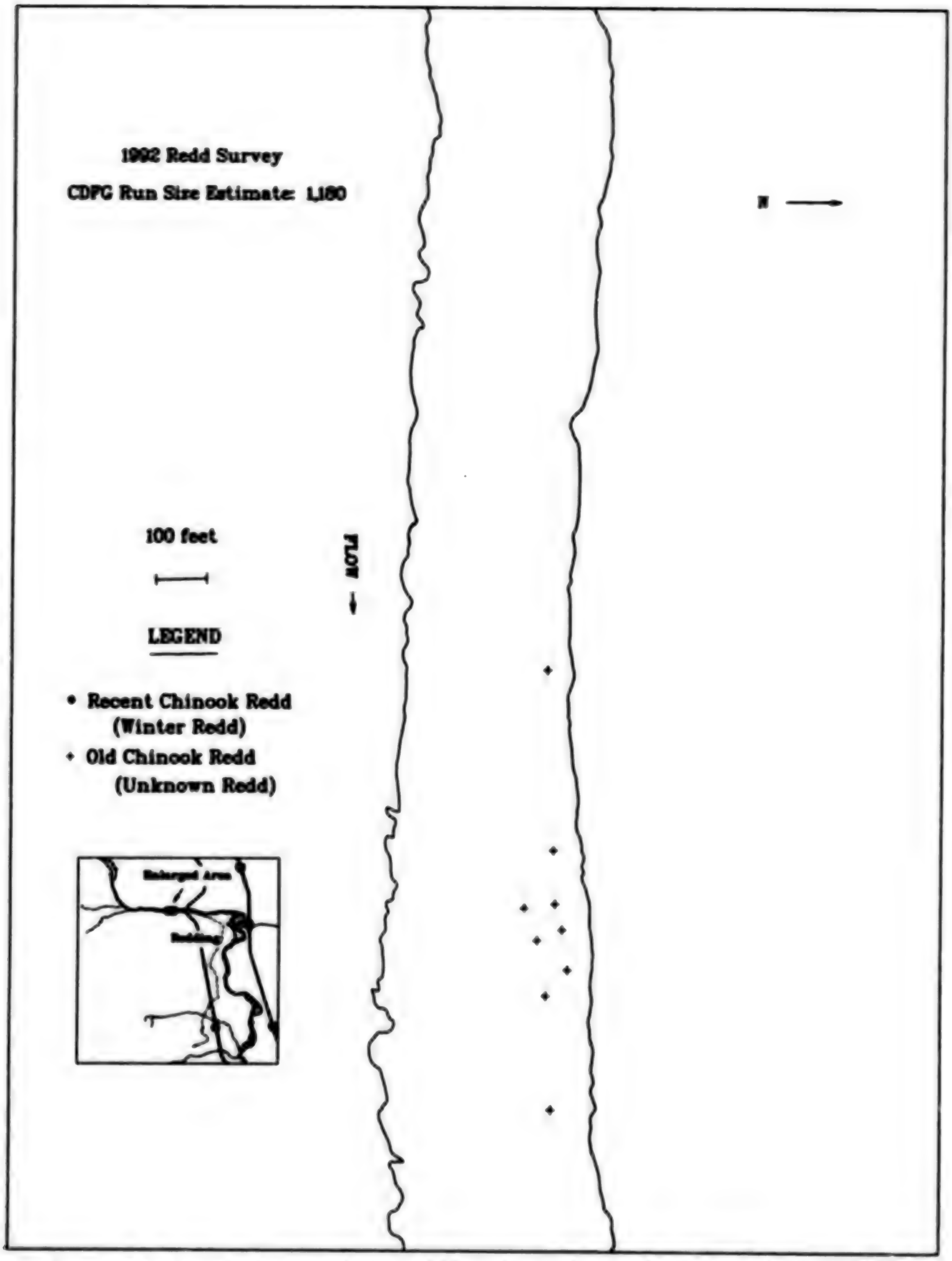
Appendix 30d.—Chinook salmon redd locations, observed by SCUBA survey, in the index area of the Sacramento River, 1991, section 4 of 4. Two transects along the north bank of the river were surveyed where chinook redds had been previously observed.


Diestelhorst Bridge
1992 Redd Survey
CDFG Run Size Estimate: 1,180
N
Southern Pacific Bridge
Boat Ramp
100 feet
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson-Cottonwood Irrigation District Diversion Dam

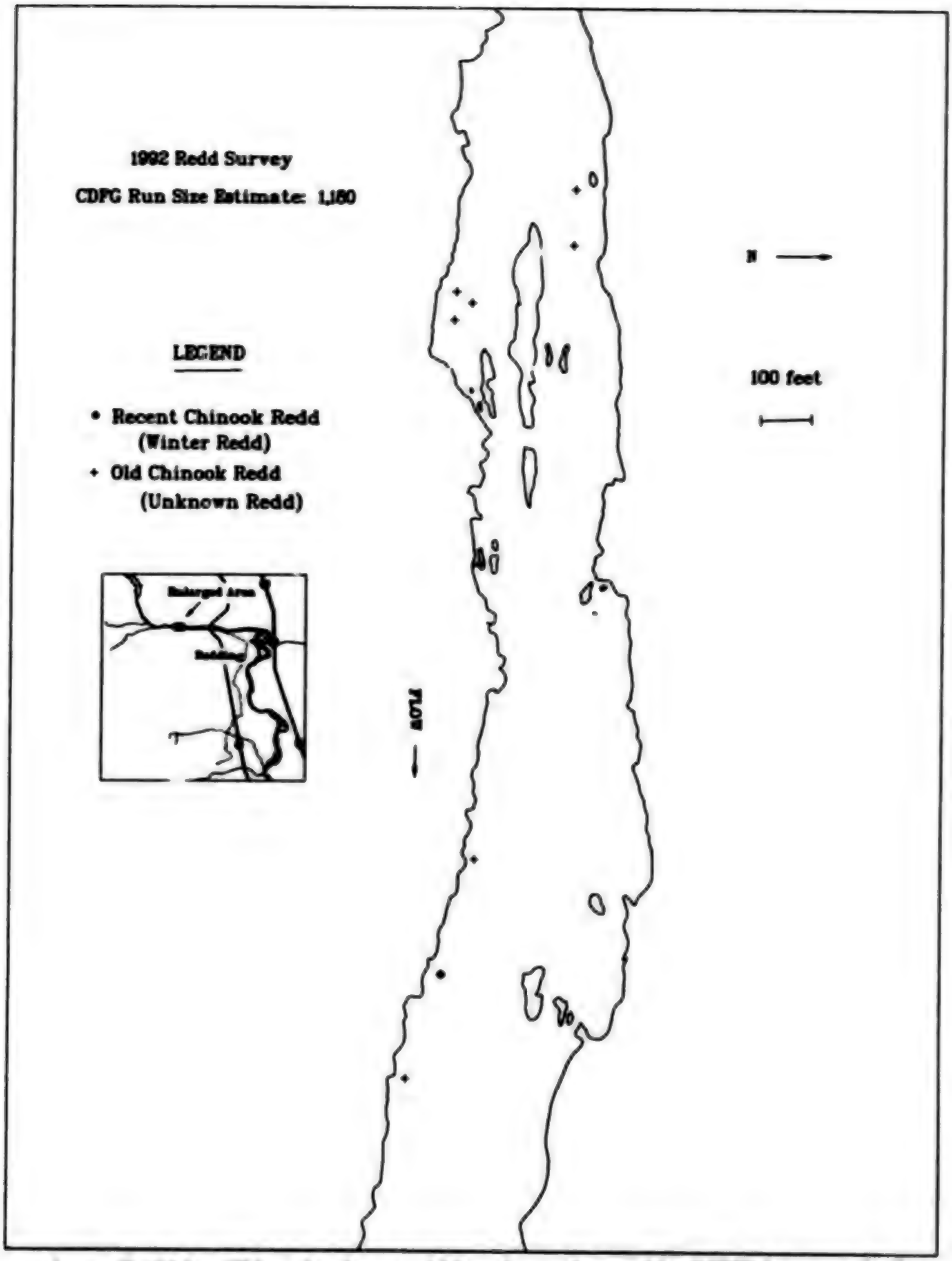
Appendix 31a.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from the ACID to Keswick dams, 1992, section 1 of 6.



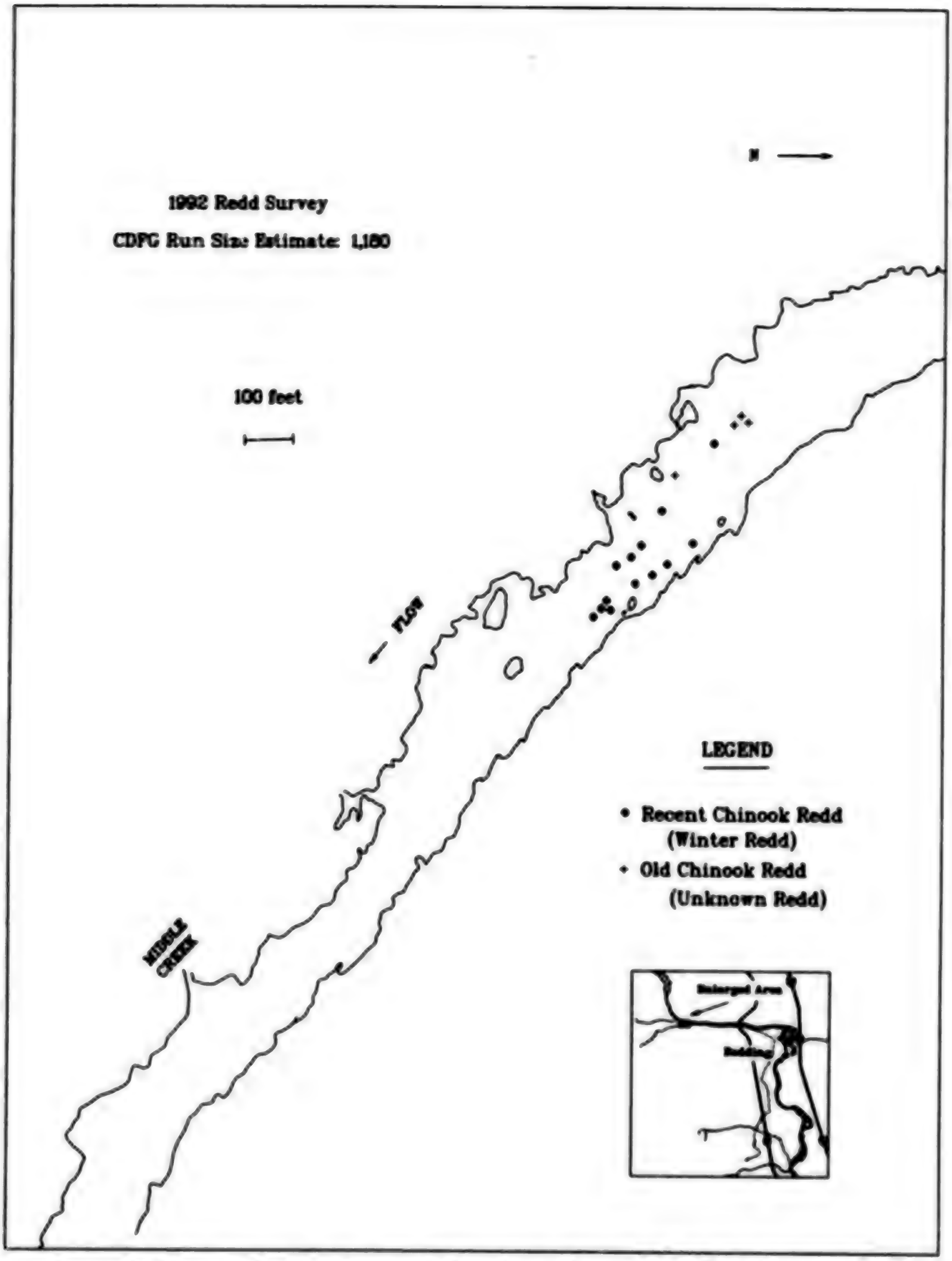
Appendix 31b.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1992, section 2 of 6.


1992 Redd Survey
CDFG Run Size Estimate: 1,180
N
100 feet
FLOW
LEGEND
• Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding

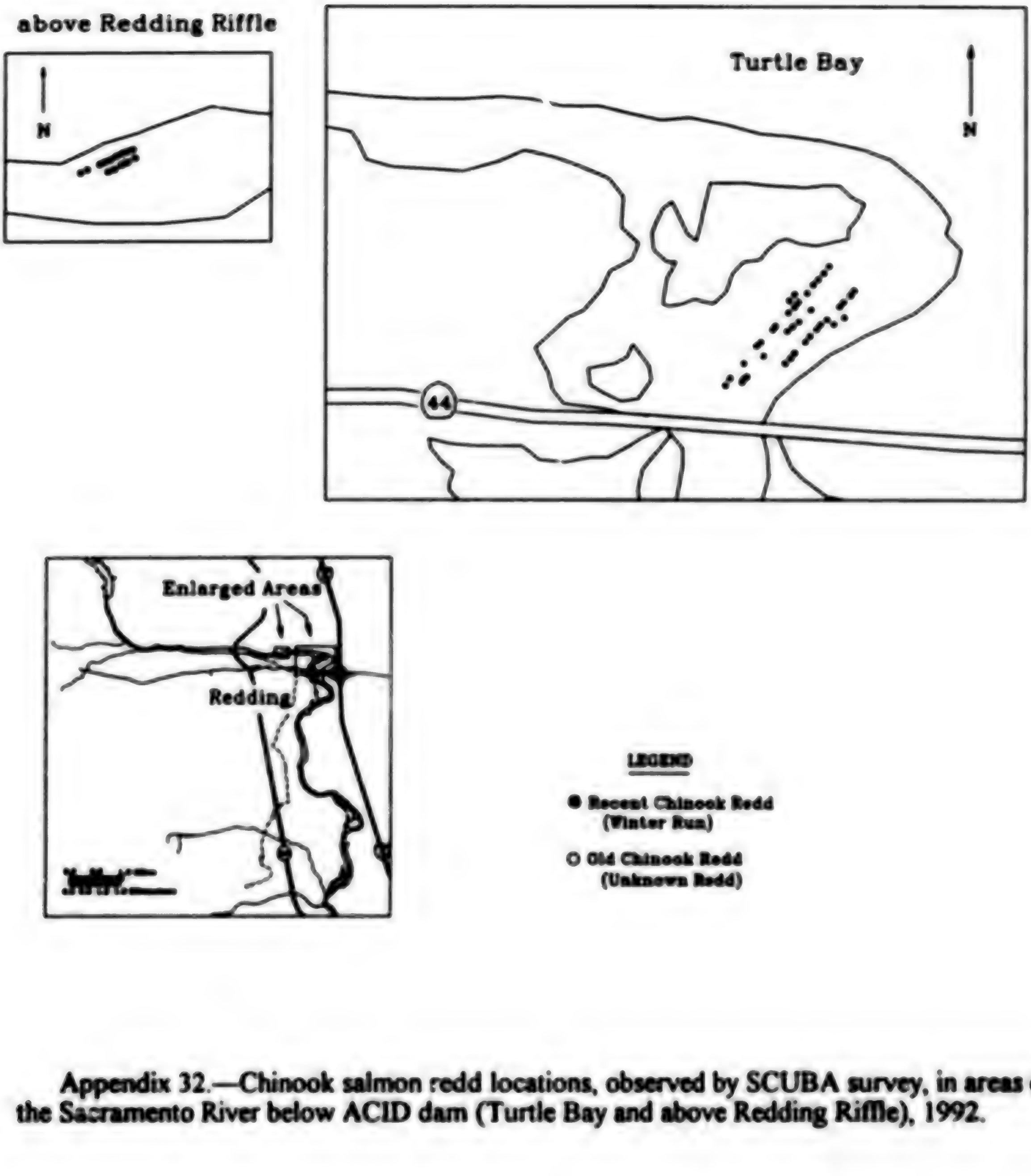
Appendix 31c.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1992, section 3 of 6.


1992 Redd Survey
CDFG Run Size Estimate: 1,180
LEGEND
● Recent Chinook Redd (Winter Redd)
+ Old Chinook Redd (Unknown Redd)
N
100 feet
FLOW
Enlarged Area
Redding

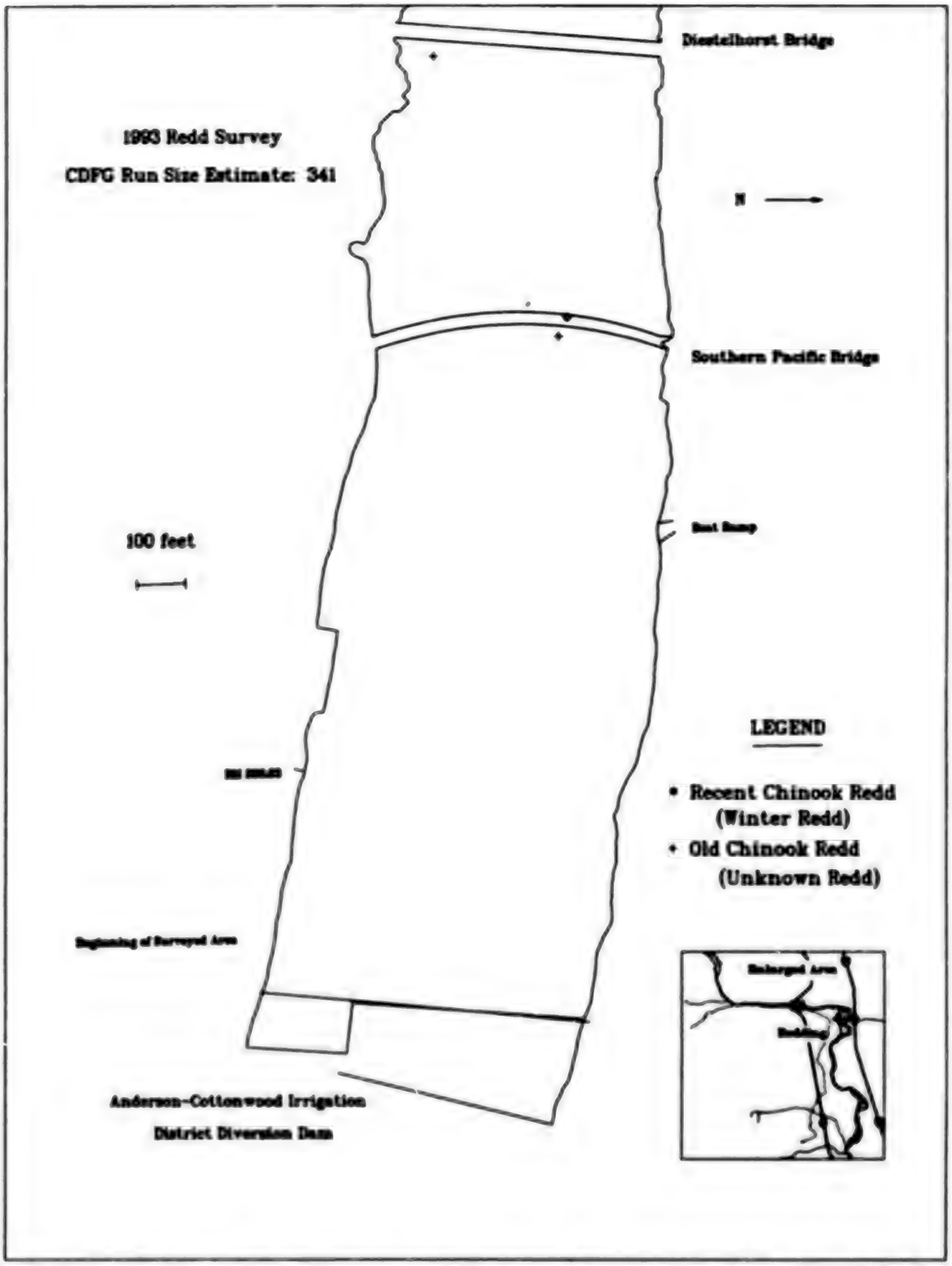
Appendix 31d.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1992, section 4 of 6.


N
1992 Redd Survey
CDFG Run Size Estimate: 1,180
100 feet
FLOW
MIDDLE CREEK
LEGEND
● Recent Chinook Redd (Winter Redd)
• Old Chinook Redd (Unknown Redd)
Enlarged Area
Redding

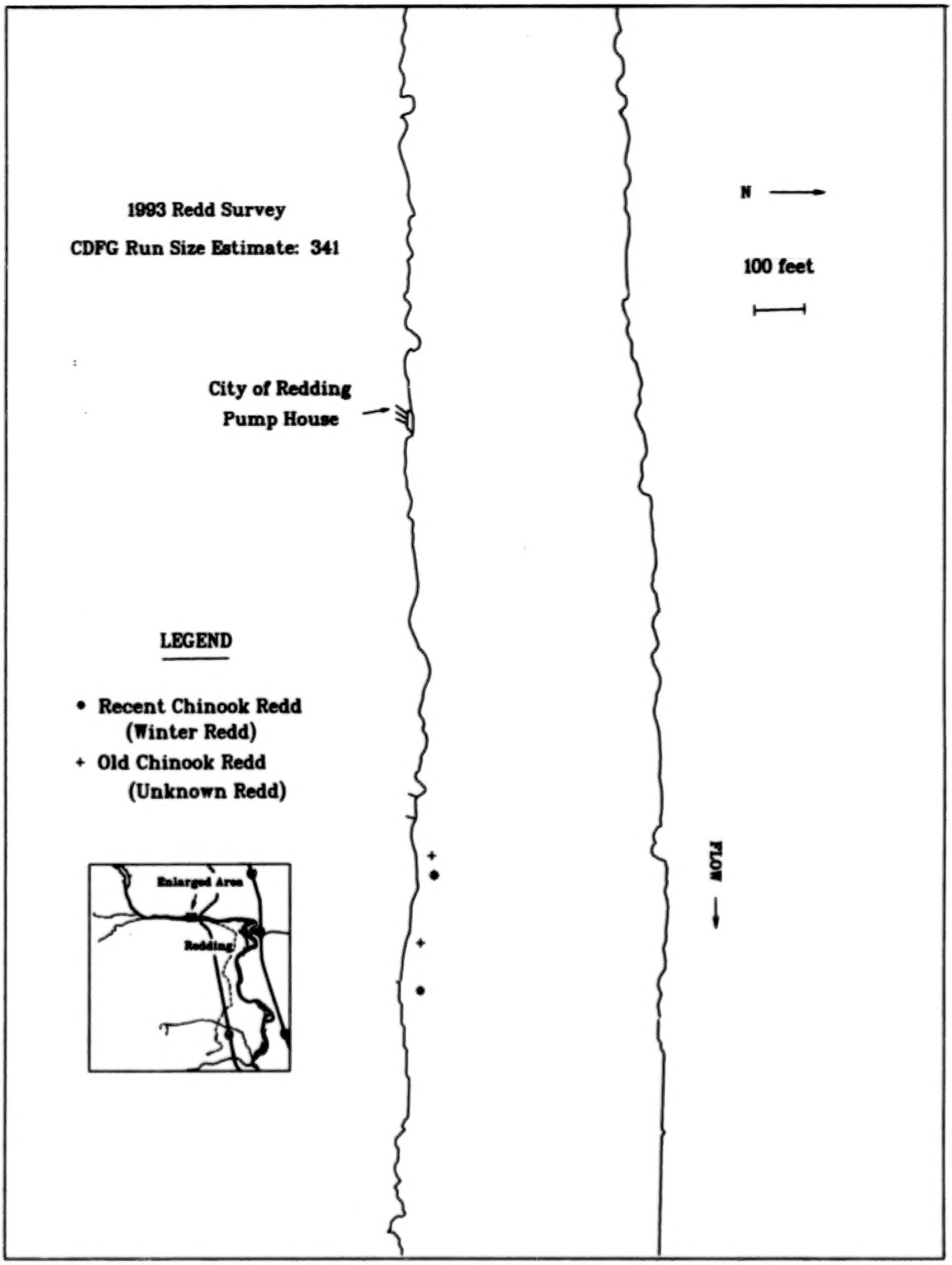
Appendix 31e.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from ACID to Keswick dams, 1992, section 6 of 6.


above Redding Riffle
N
Turtle Bay
N
44
Enlarged Areas
Redding
LEGEND
● Recent Chinook Redd (Winter Run)
○ Old Chinook Redd (Unknown Redd)

Appendix 32.—Chinook salmon redd locations, observed by SCUBA survey, in areas of the Sacramento River below ACID dam (Turtle Bay and above Redding Riffle), 1992.


Diestelhorst Bridge
1993 Redd Survey
CDFG Run Size Estimate: 341
N
Southern Pacific Bridge
Boat Ramp
100 feet
LEGEND
• Recent Chinook Redd (Winter Redd)
• Old Chinook Redd (Unknown Redd)
Beginning of Surveyed Area
Enlarged Area
Redding
Anderson-Cottonwood Irrigation
District Diversion Dam

Appendix 33a.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from Anderson-Cottonwood District Diversion Dam to Keswick Dam, 1993, section 1 of 2.



Appendix 33b.—Chinook salmon redd locations, observed by SCUBA survey, in the Sacramento River from Anderson-Cottonwood District Diversion Dam to Keswick Dam, 1993, section 2 of 2.

Appendix J

Installation of Dam Boards at ACID

Appendix 34.—Date of installation of dam boards at Anderson-Cottonwood Irrigation Diversion in the Sacramento River, 1987-1993.

	Date Anderson-Cottonwood Irrigation District dam boards were placed	
Year	In	Out
1993	April 19-22	October 20
1992	April 15-17	October 27
1991	April 10	November 14
1990	April 9	November 5
1989	April 22	November 1
1988	March 23	November 8
1987	March 30	November 3

END

05/22/97